669.106
I:71

MAY 1947

Sci
STACKS
REFERENCE
DO NOT LOAN
JUN 27 1947
PUBLIC

JOURNAL OF THE IRON AND STEEL INSTITUTE

4 GROSVENOR GARDENS · LONDON · S·W·1

Established 1869 · Incorporated by Royal Charter 1899

VOL. 156 PART I

Principal Contents

Developments in the Use of Blast-Furnace Gas at the Port Kembla Steelworks..*by H. Escher*

The Application of Single Crystals to the Study of Tempered Martensite..*by G. Kurdjumov and L. Lyssak*

Some Experiments on Quenching Media..*by F. W. Jones and W. I. Pumphrey*

The Distribution of Fuel in Gas Producers..*by M. L. Hughes*

A Photo-Electric Pyrometer for a Small High-Frequency Induction Furnace..*by T. Land and H. Lund*

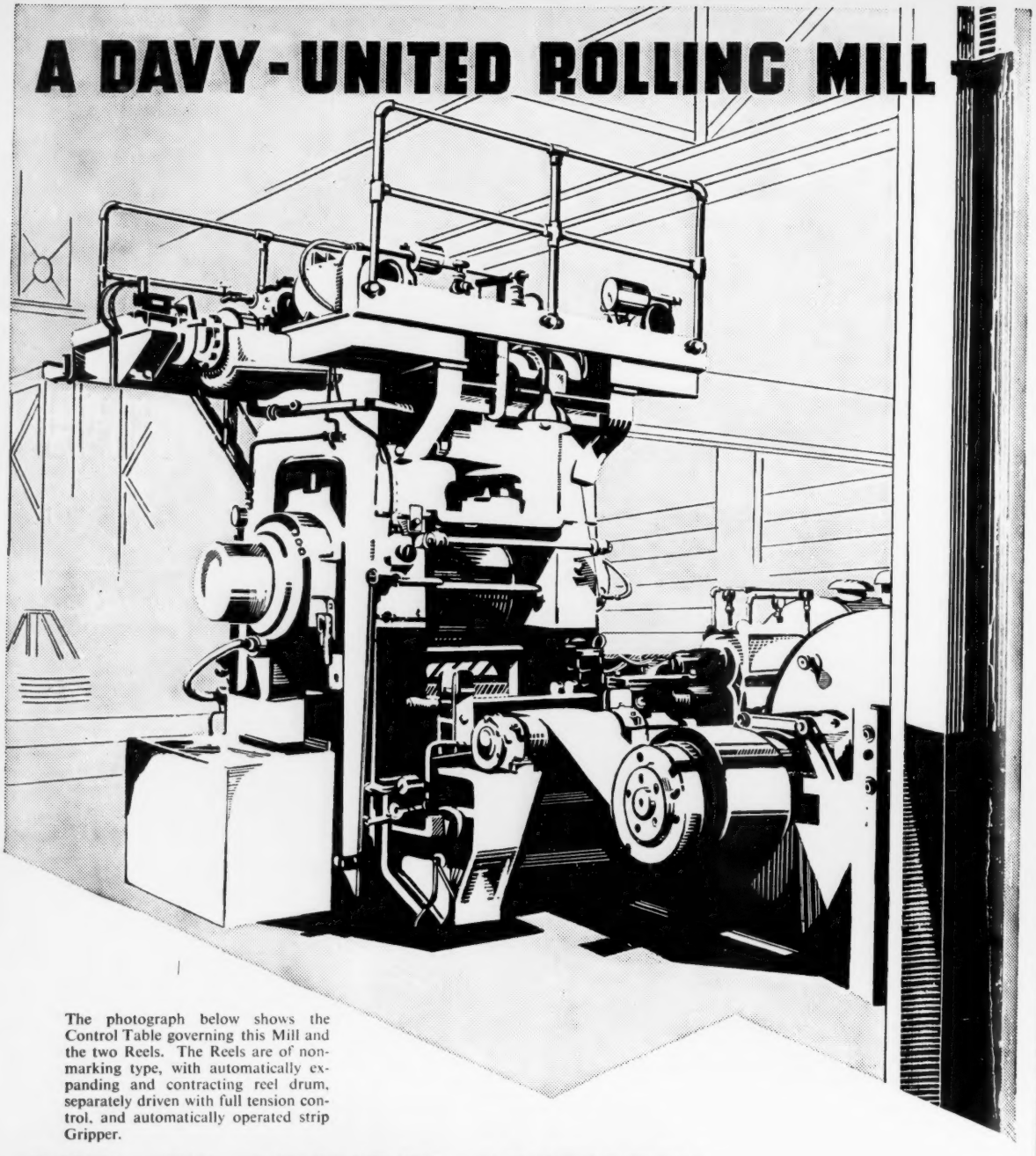
Steam Turbines for Iron and Steel Works..*by I. V. Robinson*

Water-Tube Boilers for Iron and Steel Works

Gas Turbine Applications in Iron and Steel Works..*by A. T. Bowden, W. H. Gibson, J. W. Railly and R. G. Voysey*

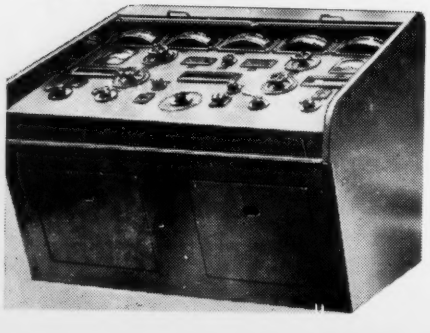
News and Abstracts

A DAVY-UNITED ROLLING MILL



The photograph below shows the Control Table governing this Mill and the two Reels. The Reels are of non-marking type, with automatically expanding and contracting reel drum, separately driven with full tension control, and automatically operated strip Gripper.

AND ITS CONTROL ASSEMBLY



This 10¼ in. and 28 in. by 24 in. Four-High Reversing Cold Strip Mill, is suitable for cold rolling mild steel strip up to 20–21 in. wide. Speed 500-1,000 ft. per minute. It has these special features:

Back-up Rolls fitted with Morgoil bearings.

Self-contained hydraulically operated top roll balance system. Two Motor operated screwdown with Selsyn indicator, the bottom casing of the enclosure formed integral with the roll housings, preventing escape of oil.

Totally enclosed combination drive and pinion stand.

DAVY AND **UNITED ENGINEERING**
COMPANY LIMITED SHEFFIELD

Proprietor of: Duncan Stewart & Company Limited, Glasgow.
Davy and United Roll Foundry Limited, Billingham.
Associated with: United Engineering and Foundry Company, Pittsburgh, U.S.A.

JOURNAL of THE IRON AND STEEL INSTITUTE

VOL. 156 PART 1

MAY 1947

Editor . . K. HEADLAM-MORLEY
Technical Editor . . A. E. CHATTIN, B.Sc. (Hons. Met.) A.R.I.C., F.I.M.
Managing Editor . E. R. MORT, B.Sc., F.I.M.
Assistant Editor . . C. R. HARMAN, B.Sc. (Eng.)

PUBLISHED MONTHLY
Editorial contents copyright by THE IRON AND STEEL INSTITUTE
EDITORIAL AND ADVERTISEMENT OFFICES
4, Grosvenor Gardens, London, S.W.1
Telephone : SLOane 0061
Telegrams : Irosamente, Sowest, London

SUBSCRIPTIONS
Members : Free
Extra Copies 7s. 6d. each
Non-Members : £5 . 0 . 0 per annum
Single Copies 10s. each

NOTE : The Institute as a body is not responsible for statements made, or opinions expressed, in papers, articles or discussion appearing in the Journal of the Iron and Steel Institute.

CONTENTS

IRON AND STEEL INSTITUTE PAPERS

"Developments in the Use of Blast-Furnace Gas at the Port Kembla Steelworks" *by H. Escher* 1

Historical Note No. 2
"A Factory Doctor's Duties at an Ironworks in 1724" *by H. R. Schubert* 27

"The Application of Single Crystals to the Study of Tempered Martensite" *by G. Kurdjumov and L. Lyssak* 29

"Some Experiments on Quenching Media" *by F. W. Jones and W. I. Pumphrey* 37

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

"The Distribution of Fuel in Gas Producers" *by M. L. Hughes* 55

"A Photo-Electric Pyrometer for a Small High-Frequency Induction Furnace" *by T. Land and H. Lund* 75

"The Direct Reading of Spectral-Line Intensities" *by J. H. Oldfield* .. 78

IRON AND STEELWORKS ENGINEERING

"Steam Turbines for Iron and Steel Works" *by I. V. Robinson* 81

"Water-Tube Boilers for Iron and Steel Works" *by the Water-Tube Boilermakers' Association* 90

"Gas Turbine Applications in Iron and Steel Works"
Pt. I— "Power Applications" *by A. T. Bowden* 98
Pt. II— "Blast-Furnace Applications"
Section I—"The Axial Blower" *by W. H. Gibson* .. 104
Section II—"The Bled-Axial Gas Turbine Blower" *by J. W. Railly* 108
Section III—"Operation and Control of the Bled-Axial Gas Turbine Blower" *by R. G. Voysey* .. 113

NEWS

Institute Meetings . . Symposium on Powder Metallurgy 119
News of Members 121
Iron and Steel Engineers Group 122
The British Iron and Steel Research Association 122
Institution of Metallurgists 122
Mond Nickel Fellowships . . Education 123
American Institute of Mining and Metallurgical Engineers 124
Translations 126

ABSTRACTS and BOOK REVIEWS

Contents 127
Abstracts .. .. 127—143
Book Notices 143
New Publications 144

A special notice relating to Special Report No. 36—Symposium on Hardenability—appears on p. 39 of the Advertisement Section.

The Wellman Smith Owen Engineering Corporation Limited

Head Office:

Victoria Station House, Victoria Street, London, S.W.1

Works: Darlaston, South Staffs.

We design and construct:

OPEN HEARTH STEEL MELTING FURNACES — METAL MIXERS
REHEATING FURNACES — SOAKING PITS — GAS PRODUCERS
FURNACE CHARGING MACHINES — COKE OVEN MACHINERY
SPECIAL STEELWORKS CRANES — WELDLESS STEEL TUBE PLANT
INGOT STRIPPERS — LADLE CRANES — SHEET MILL EQUIPMENT
LEVEL LUFFING JIB CRANES FOR DOCKS AND HARBOURS

COMPLETE STEELWORKS INSTALLATIONS

MOBILE FORGING MANIPULATOR

DR. C. SYKES, F.R.S.

CHARLES SYKES, D.Sc., Ph.D., F.Inst.P., F.R.S., became Director of the Brown-Firth Research Laboratories in 1944 in succession to the late Dr. W. H. Hatfield, F.R.S. Born on 27th February, 1905, he was educated at Staveley, Netherthorpe Grammar School, and the University of Sheffield. He graduated in Science in 1925, then spent a year carrying out research in physics under Professor R. S. Milner, F.R.S. ; having obtained his Degree of Master of Science in 1926, he entered the Metallurgy Department, Sheffield University, under Professor C. H. Desch, F.R.S., as a Metropolitan-Vickers Research Scholar. Two papers on the alloys of zirconium (Journal of the Institute of Metals, 1928 and 1929) appear to represent the first fruits of his work as a metallographer.

Since 1928, Dr. Sykes was connected with the research organisation of the Metropolitan-Vickers Electrical Co., Ltd., being engaged at first on work of high-vacuo thermionic valves and X-ray tubes. About 1934, under the influence of Professor W. L. Bragg, F.R.S., he began to publish, in the Proceedings of the Royal Society and the Journal of the Iron and Steel Institute and later in the Proceedings of the Physical Society and the Journal of the Institute of Metals, a remarkable series of papers on the superlattice, the order/disorder change in beta brass and other alloys, on the supposed low-temperature critical points in iron and steel and on age-hardening. Some sixteen papers, all of real importance, represent the contribution that Dr. Sykes has made in little more than five years to that field of knowledge which is concerned with the physics of the metallic state.

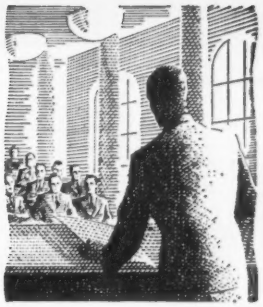
In 1940, Dr. Sykes succeeded Dr. Desch as Superintendent of the Metallurgy Division of the National Physical Laboratory, Teddington.

During the war Dr. Sykes was engaged on a variety of problems concerning ballistics, armour-piercing shot, armour plate and the sabot shell.

Dr. C. Sykes, F.R.S.
Second Hatfield Memorial Lecturer, 1947

IRON AND STEEL
INSTITUTE PAPERS

PLANT DESIGN · MANUFACTURE · RESEARCH · DEVELOPMENT



Developments in the Use of Blast-Furnace Gas at the Port Kembla Steelworks*

By H. Escher†

CONTENTS

	PAGE
I—INTRODUCTION	1
II—GENERAL CONSIDERATIONS IN THE UTILIZATION OF BY-PRODUCT FUELS	2
III—BLAST-FURNACE-GAS SUPPLY AND REGULATION	
(*a*) Gas Production	3
(*b*) Gas Distribution	4
(*c*) Gas Quality	5
(*d*) Leakage and Bleeding	5
(*e*) Effect of Charging on Gas Supply ...	7
(*f*) Automatic Variable Firing on Blast-Furnace Stoves	7
(*g*) Automatic Bleeder Control	9
IV—EFFECTS OF FUEL REDISTRIBUTION ON OPEN-HEARTH OPERATION	10
V—SOAKING PITS	
(*a*) Original Layout	12
(*b*) Experimental Soaking Pit	13
(*c*) Blast-Furnace-Gas-Fired Ten-Ingot pits	13
(*d*) Combustion Conditions	16
(*e*) Operating Experience with High-Temperature Recuperators ...	16
(*f*) Performance	16
(*g*) Design Considerations	16
VI—TEN-INCH-MILL CONTINUOUS HEATING FURNACE	
(*a*) Operating Experience with Original Coke-Oven-Gas-Fired Furnace ...	18
(*b*) Conversion to Blast-Furnace-Gas Firing	18
(*c*) Operating Results	23
(*d*) Quality of Heating	24
(*e*) Furnace for New Rod-and-Strip Mill	25
VII—GAS HAZARDS	26
VIII—RESULTS AND OUTLOOK	26
IX—ACKNOWLEDGMENTS	27

I—INTRODUCTION

STEELMAKING at Port Kembla during the war years had to struggle against acute shortages of fuels and labour, a condition which progressed in severity towards the end. The extension of blast-furnace gas for heating at the mills, initiated in 1941–2, played a big part in providing relief. A large number of gas producers have been shut down, and relatively inefficient producer-fired steel furnaces have been converted to firing with by-product fuels. It was found that rolling-mill production, which largely depended on an adequate supply of coke-oven gas, could be maintained on blast-furnace-gas firing when little or no coke-oven gas was available for these units. All this has resulted in substantial improvements in steelworks practice.

The use of blast-furnace gas under steam boilers at the Port Kembla steelworks was reviewed by the author in a previous paper.‡ At that time blast-furnace gas was used only for steam-raising and for heating the blast-furnace stoves. The present paper deals with some aspects of blast-furnace-gas supply and regulation, with developments which have taken place in the use of this fuel for heating steel, and with the effects of these changes on overall fuel consumption and on steelworks practice in general.

The production of iron and steel at the Port

* Received 27th August, 1946.

† Australian Iron and Steel, Ltd., Port Kembla, New South Wales.

‡ *Journal of the Iron and Steel Institute*, 1939, No. I, pp. 443P–477P.

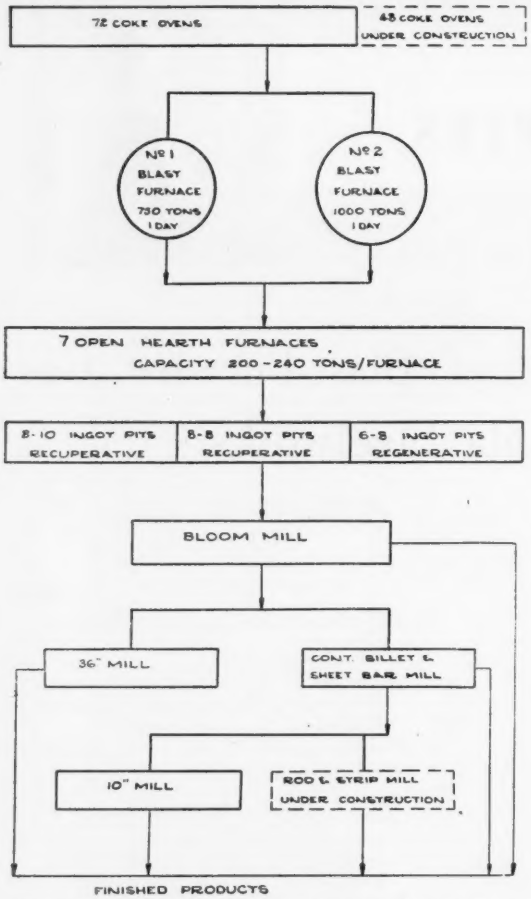

72 COKE OVENS
48 COKE OVENS UNDER CONSTRUCTION
No 1 BLAST FURNACE 730 TONS 1 DAY
No 2 BLAST FURNACE 1000 TONS 1 DAY
7 OPEN HEARTH FURNACES CAPACITY 200-240 TONS/FURNACE
8-10 INGOT PITS RECUPERATIVE
8-8 INGOT PITS RECUPERATIVE
6-8 INGOT PITS REGENERATIVE
BLOOM MILL
36" MILL
CONT. BILLET & SHEET BAR MILL
10" MILL
ROD & STRIP MILL UNDER CONSTRUCTION
FINISHED PRODUCTS

FIG. 1—Diagrammatic layout of main works units

Kembla works is favoured by the high quality of the raw materials used. However, a low rate of coke consumption at the blast-furnace results in relatively small quantities of by-product fuels, so that economic use of these is particularly important. The Company owns several collieries in the vicinity of the steelworks, and the coal from these collieries yields an excellent metallurgical coke. The carbonizing plant of 72 Wilputte by-product ovens has a maximum production capacity of 47,500 tons of coke per month. This is not sufficient to meet requirements, and an additional battery of 48 ovens is under construction.

As shown in Fig. 1, the two blast-furnaces have a combined capacity of 1750 tons of pig iron per day, but higher rates have been maintained in continuous operation. The hot metal is conveyed to the melting shop in 120-ton mixer-type ladles. The melting shop has seven large stationary open-hearth furnaces, of 200–240 tons holding capacity, and a 1200-ton mixer. The ingots are heated in 22 soaking pits, which have a total holding capacity of 192 ingots of 4·4 tons weight. The electric blooming mill feeds the 36-in. structural-shapes and rail mill or, alternatively, the continuous billet and sheet-bar mill. This latter mill has a steam-driven breakdown stand and a train of six stands driven through gears from a 6000-h.p. motor.

A wide range of merchant sizes is rolled in the 10-in. mill, and a new double-strand rod-and-strip mill is now under construction.

The proportion of finished products during the past twelve months was as follows :

Slabs	3·1%
Sheet bar and sales billets	44·8%
Rails	11·1%
Structural shapes	6·9%
Merchant bar and shapes	33·4%
Other products	0·7%

These proportions may vary considerably, depending on the market requirements.

II—General Considerations in the Utilization of By-Product Fuels

The total amount of blast-furnace gas produced at Port Kembla during full operation is equivalent to 250,000 tons of coal per year, and the total amount of coke-oven gas produced is equivalent to 150,000 tons of coal per year, making about 400,000 tons of equivalent coal in the form of gaseous by-products. Tar made at the ovens is equivalent to 25,000 tons of coal per year ; this tar is of considerable importance as a promoter of flame luminosity in the open-hearth furnaces. In addition to the above items, the coke breeze accounts for another 40,000 tons of equivalent coal per year, so that the total by-product fuels represent nearly half a million tons of coal, and the efficient use and allocation of these fuels has a considerable bearing on production and economy.

The local coal is, as previously stated, a good coking coal but is inferior as a producer-gas coal, and substantial benefits have been obtained by changing over from producer-gas to by-product-fuel firing ; this is particularly true in the case of the melting shop. The combined benefits of the greatly reduced fuel rate per ton of ingots, the increased output owing to more flexible firing conditions, the more accurate control, the lower furnace-maintenance cost owing to the simpler furnace construction, and the reduced labour requirements, result in a very substantial difference in steelmaking cost in favour of tar and coke-oven-gas firing over producer-gas firing.

The distribution of interworks coke-oven gas from 1942 until 1946 is shown in Fig. 2. In 1942 the soaking pits and the 10-in. mill reheating furnace absorbed 46–50% of the total interworks gas (total gas less coke-oven-fuel gas). The conversion of these units to blast-furnace-gas firing therefore provided ample scope for the saving of coke-oven gas.

In 1941–2 one of the soaking pits was converted to mixed blast-furnace-gas and coke-oven-gas firing, using a new type of metallic recuperator for preheating both the air and the blast-furnace gas. In the course of the next twelve months the remaining 15 continuous-fired pits were converted on similar lines, the last group of eight using only blast-furnace gas. These pits were originally fired with gas from hand-fed producers, but the gas from these was poor and insufficient, and it had to be supplemented by considerable quantities of coke-oven gas.

The conversion of the 16 producer-gas and coke-oven-gas fired soaking pits was particularly attractive because the fuel consumption and the maintenance of these pits and producers were high. Following the completion of the soaking-pits conversion, the 10-in. mill furnace was also reconstructed for firing with blast-furnace gas. The remarkable change in distribution of coke-oven gas between 1942 and 1944 is shown in Fig. 2; during the period mentioned, the proportion of coke-oven gas used in the open-hearth plant increased from 33% to 78%, whereas the combined consumption of the 10-in. mill and the soaking pits dropped from 48% to 12%. As a result of this, relatively inefficient producer-gas-fired open-hearth furnaces were changed over to tar and coke-oven-gas firing. The overall effects of these changes on fuel consumption are discussed at the end of this paper.

The coke ovens are at present fired with coke-oven gas, but they can be converted to blast-furnace-gas firing. The use of blast-furnace gas at the coke ovens would involve major alterations such as long pipelines, new electrostatic precipitators for gas cleaning, and a gas-holder to assure a steady supply of gas when only one blast-furnace is in operation. Developments along these lines will probably take place with future major expansion of the works.

Blast-furnaces are less reliable than coke ovens as a source of gas supply, and to cope with the case of only one blast-furnace being in operation, and also not having any gas-holders, certain provisions had to be made in the design of heating equipment for the use of alternative fuels. At the 10-in. mill furnace either blast-furnace gas or coke-oven gas can be used singly or mixed in any proportion at any time. To minimize the effects of the rather severe pressure fluctuations and of the changes in supply and demand of blast-furnace gas, an automatic variable-firing system which utilizes the heat-storage capacity of the brick-work was installed on the blast-furnace stoves. On the soaking pits the proportion of the two fuels can also be varied.

The metallic recuperators used in these furnace conversions will be described later in the present paper. In all, 59 units of this type have been built or are under construction. At present a new glass tank in Sydney is being fitted with this type of recuperator for preheating air to a temperature of up to 1400° F. On an experimental open-hearth furnace of 4 tons capacity, preheats of up to 1400° F. have been obtained, and flue gases at 3000° F. are handled by the recuperator without precooling.

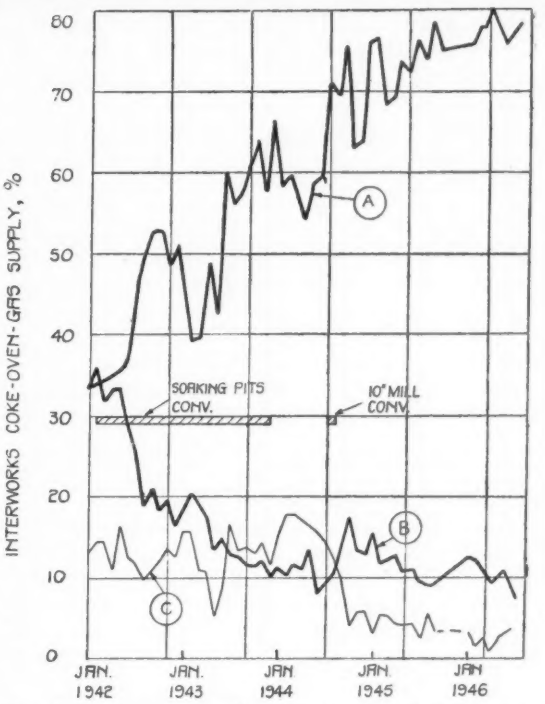


FIG. 2—Coke-oven-gas distribution, 1942–1946. Curve *A*, open-hearth plant; curve *B*, soaking pits; curve *C*, 10-in. mill

III—Blast-Furnace-Gas Supply and Regulation

(a) *Gas Production*

The volume of blast-furnace gas made per ton of iron is closely related to the quality of the ore smelted. During the war some local New South Wales ores of medium grade were used, together with the regular high-grade ores from Whyalla, South Australia. The average analyses of these two ores were as follows:

	South Australian Ores	New South Wales Ores
Moisture, %	1·0	3·0
Insoluble, %	3·4	18·0
Manganese, %	2·0	0·3
Iron, %	63·0	51·0
Phosphorus %	0·0	0·2

The performance of No. 2 blast-furnace on a

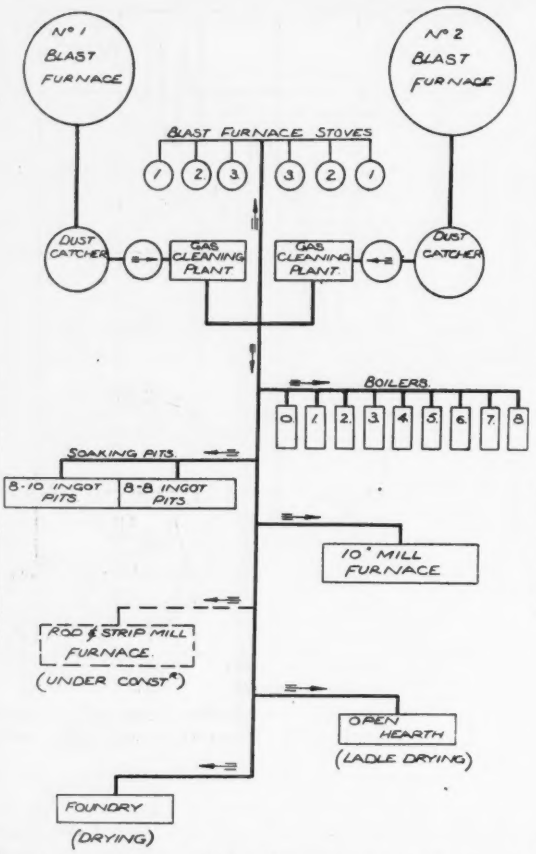


FIG. 3—Diagram of blast-furnace-gas system

straight Whyalla ore burden and on a mixture of 67% of Whyalla and 33% of the local New South Wales ores is shown in Table I. The considerably greater amount of blast-furnace gas made per ton of iron when smelting the lower-grade ores is offset to a certain extent by increased steam consumption at the blower and higher gas consumption in the stoves.

TABLE I—*Comparative Blast-Furnace Performance with Two Different Ore Burdens (No. 2 Furnace)*

	100% Whyalla	67% Whyalla and 33% New South Wales
Pig-iron production, tons/day ...	1250	1000
Net coke consumption, lb./ton of iron ...	1725	2060
Ash content of coke, %...	18·0	18·0
Gas/ton of coke, cu. ft. ...	136,500	136,500
Gas/ton of iron, cu. ft. ...	105,000	125,000
Calorific value of gas, B.Th.U./cu. ft. ...	90·0	93·1
B.Th.U. produced per ton of iron ...	9,500,000	11,700,000

The low rate of blast-furnace-gas production per ton of iron at Port Kembla is naturally also accompanied by a corresponding low rate of coke-oven-gas production. The coal used at Port Kembla has an average volatile content of 23%, and the coke yield is 73·5%. The gas yield per ton of coal varies between 10,500 and 11,000 cu. ft. The total heating value of the coke-oven gas per ton of iron produced is therefore approximately 6,500,000 B.Th.U. The combined heating value of the blast-furnace and coke-oven gases is 16,000,000 B.Th.U./ton of iron, and rises to 19,500,000 B.Th.U./ton for the lower grade of ore mixture. About 50% of the heat in the coke is returned in the blast-furnace gas.

(b) *Gas Distribution*

The blast-furnace-gas distribution system is shown in Fig. 3. The gas from the furnaces passes first through the dustcatcher, thence to the washer tower, and is finally cleaned in Theisen disintegrators. The distribution of gas for an average month on normal production is as follows :

	Gas, %	Gas, millions of cu. ft.
Production	100·00	5333
Leakage	12·65	672
Metered bleeding ...	1·50	80
To blast-furnace stoves	17·25	920
To interworks system ...	12·10	645
To boilers	56·50	3013

The total gas is metered first in the long vertical main after the washer tower by means of a circular orifice. After the Theisen disintegrators the gas to each of the main consuming units is again metered. This double metering provides a ready means of checking the accuracy of the instruments.

The gas after the disintegrators has a dust content of 0·01 grains/cu. ft., but at times the dirty wash water from the disintegrators is not effectively separated in the water eliminators and this sludge is carried into mains and equipment, causing trouble which becomes progressively greater the smaller the size of the main and valves. For instance, on the 10-in. mill, where the size of the supply main and valves is 30-in., no cleaning has been required over a period of two years. At the soaking pits where the valves are only 10 in. in dia., cleaning of the valves and of the inlet to the recuperators is necessary every six months.

Once the gas has been heated, the dry dust in the gas causes no trouble in the recuperator, mains, or burners. However, such dust, if it is heated to a high temperature in the combustion process, may be deposited on brickwork, particularly when the gas is flowing through small apertures.

The blast-furnace-gas main to the soaking pits

is 1500 ft. long. Deposit is heaviest at the blast-furnace end of the main, being up to 2 in. thick at the top and less at the bottom of the main. The thickness of the deposit at the soaking-pits end is about $\frac{1}{8}$–$\frac{1}{4}$ in. Only the first section of the main is cleaned, and this is done by washing-down with a fire hose once every 18 months or so, depending on opportunity. Mud also deposits in rings around the circumferential butt-welds, and these disturbances to the flow, occurring at frequent intervals, increase the coefficient of friction quite appreciably, even in the clean main.

(c) *Gas Quality*

The calorific value of blast-furnace gas may vary by 4–6 B.Th.U./cu. ft. over short periods of from 15 min. to 1 hr., and even greater fluctuations may take place from day to day and from week to week. With two furnaces in operation these fluctuations are smaller in the mixture of gas after the cleaning plant. The effect of a change in calorific value from 85 to 95 B.Th.U./cu. ft. on the performance of units such as a soaking-pit or a continuous steel-heating furnace operating at about 2400° F. is quite appreciable, because the effective flame temperature is not much above the working temperature, and 10 B.Th.U./cu. ft. corresponds to about 100° F. in flame temperature for the above conditions. Normal fluctuations in the calorific value of coke-oven gas have practically no effect on such units, because the effective flame temperature is well above the working temperature.

The average calorific value of the blast-furnace gas is 92 B.Th.U./cu. ft. Some typical analyses at different calorific values are as follows :

Calorific Value, B.Th.U./cu. ft.	CO_2, %	CO, %	H_2, %
99·5	12·6	28·7	2·6
96·5	12·5	28·0	2·4
91·0	12·5	26·9	1·8
88·5	14·0	25·8	2·1
84·5	14·6	24·7	1·9

(d) *Leakage and Bleeding*

It has already been shown that nearly $\frac{1}{8}$th of the total gas produced is lost by leakage. This quantity cannot be measured, and the figure is obtained as the difference between the total gas make computed from the carbon balance and the total washed gas as metered by means of orifices.

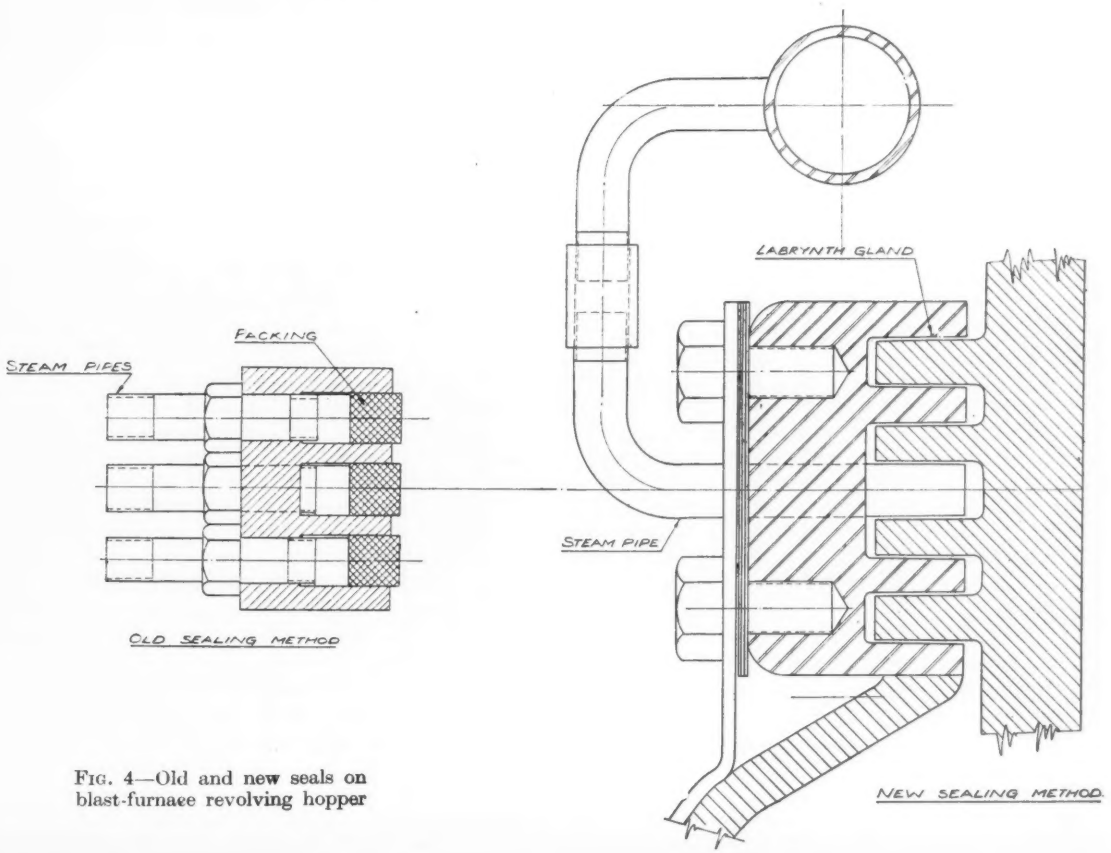


FIG. 4—Old and new seals on blast-furnace revolving hopper

The carbon-balance method is not very reliable, and the leakage figure should be regarded more as a guide than an absolute measure of leakage. However, the high order of the leakage figure stresses the importance of keeping the furnace top in good order and also of maintaining the top-gas pressure as low as possible. The average blast-furnace top pressure is 23 in. W.G., and it is expected that this pressure will be reduced after certain modifications to the gas-distribution system have been carried out.

A more reliable method of checking top leakage is by the nitrogen balance when both the air-blast volume and total washed gas are metered. In this case again it is necessary to estimate leakage of blast between the metering orifice and the entry point at the blast-furnace. Investigations carried out at Port Kembla show that, with double-bell charging, gas-leakage losses are about 5–15%, depending on the general condition of the furnace top.

Apart from the furnace-top leakage, gas losses occur around the bosh coolers, amounting to about 800 cu. ft./min. on a large furnace, or 1% of the total gas. At this point the gas is very rich, containing up to 34% of CO and 1·6% of CO_2. Gas is also entrained by the spray water in the wash tower and disintegrators, and this is estimated at about 0·6% of the total gas make.

Other sources of losses are the sounding-rod glands, where ample clearance is necessary to allow for bending of the rod. At Port Kembla the bells are steam operated, and sufficient leakage steam is available for sealing the sounding rods by means of a steam-sealed labyrinth gland. Exhaust steam from the large-bell gear is also used to seal the gland on the revolving hopper. Fig. 4 shows both the old and the new type of seal. The old type consisted of three rings of packing, which was difficult to maintain.

Determination of leakage losses by the nitrogen-balance method is carried out as a routine matter once a week, and the results are forwarded to the blast-furnace department with comments on the top conditions. The leakage figure of 12·65% given on page 4 has now dropped to about 8–9%. A close watch is also kept on blast leakages, as these, particularly if taking place on the hot-air side, not only involve additional fuel for extra steam for the blowers, but also extra fuel for heating the blast.

The 30-in. water-cooled hot-blast valve of the

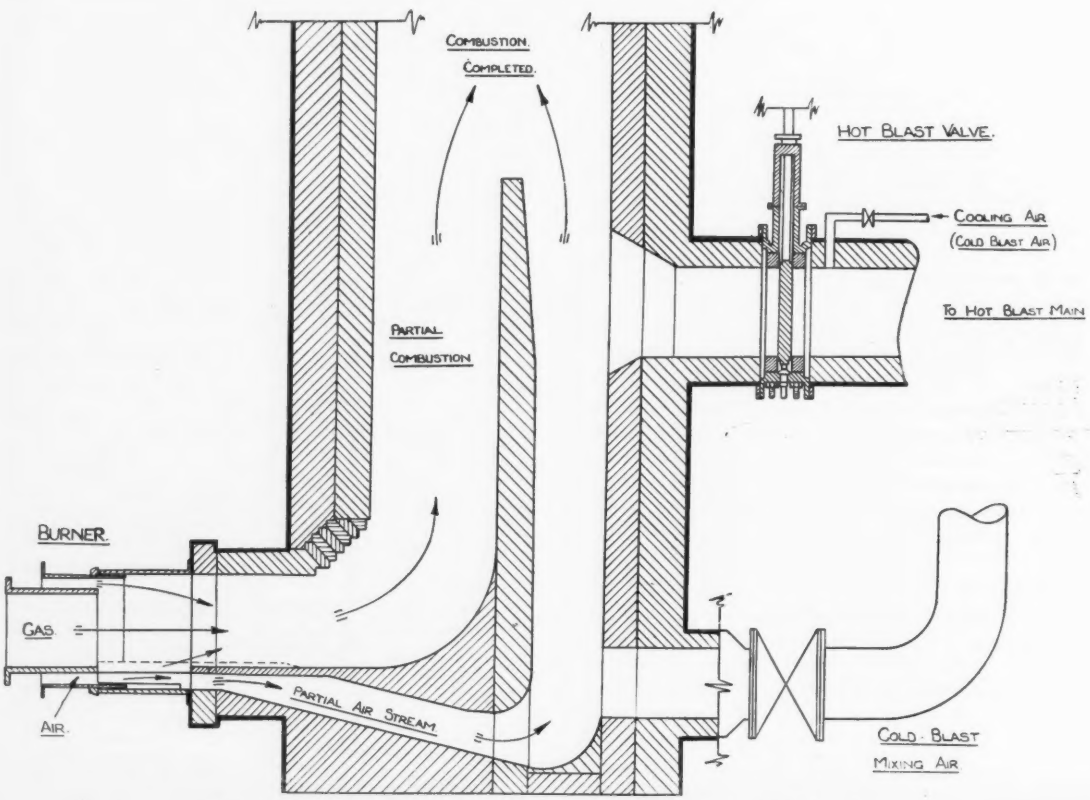


FIG. 5—Diagrammatic cross-section through stove combustion chamber

gate type as used at Port Kembla gives up an average of 1,250,000 B.Th.U./hr. to the cooling water on each stove. Modifications which have been made to one stove and are now being extended to two additional stoves reduce these losses by 750,000 B.Th.U./hr. per stove and improve the stove's efficiency by 3·7%. These modifications are illustrated in Fig. 5 and consist of:

(*a*) A vertical division wall in the combustion shaft, extending 3 ft. above the top of the hot-blast gate valve, to protect the gate and seat of the valve from radiation from the combustion chamber.

(*b*) The admission of 20% of cold combustion air (taken as part of the main air stream) into the bottom of the chamber formed by the division wall on the hot-blast-valve side to keep this chamber cool.

(*c*) A 6-in. cold-blast connection on the downstream side of the hot-blast valve, admitting about 1500 cu. ft. of cold blast per minute, so that any leakage past the hot-blast valve is composed of relatively cold air.

(*d*) The mixing air is introduced at the bottom of the chamber formed by the new division wall. This results in more uniform blast temperatures at the tuyeres of the blast-furnace than are obtained with the old method of mixing near the bustle pipe.

The above arrangement has been in service for two years, and, apart from the saving in fuel, the reduction in the heat to which the valve is exposed should result in less operational and maintenance trouble.

(e) *Effect of Charging on Gas Supply*

When the large bell is lowered to drop its charge there is an appreciable fall in gas pressure and gas flow. These frequent fluctuations make it difficult for the firemen in the boiler house to adjust the gas flow, as they cannot tell whether such a change is temporary or permanent. The drop in the rate of gas delivery from the furnace during operation of the large bell is shown in Fig. 6, and is due to two causes, namely, (*i*) increased leakage, particularly when the small bell is not seating properly, or when the glands of the revolving hopper are not in good condition, and (*ii*) the charge as it drops tends to seal the furnace top, causing a temporary reduction in gas flow. The normal gas flow from No. 2 Furnace is 85,000 cu. ft./min., and this may be reduced by as much as 30,000 cu. ft./min. when the big bell is lowered (*see* Fig. 6). Normal conditions of flow are restored in 40–60 sec.

Curves *B* (Fig. 6) show the improvement effected by repairs to the small-bell seat and gland rings. When the gas loss is due to bad seating of the small bell, it has been found that an appreciable reduction of the leakage can be effected by dumping a charge of fine ore on the small bell before the large bell is opened.

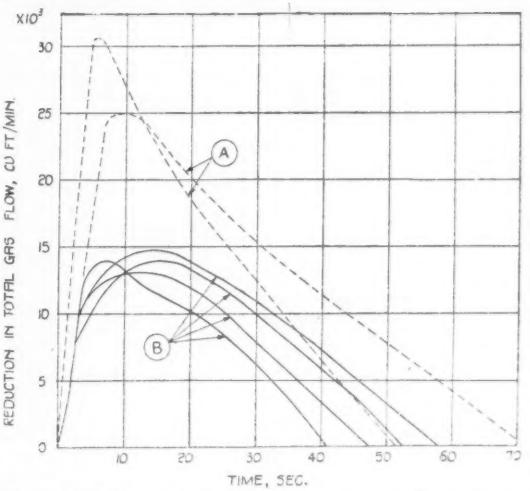


FIG. 6—Reduction in blast-furnace gas flow during charging. Curves *A*, previous to repairs to furnace top; curves *B*, after repairs to furnace top

The drop in gas volume and pressure during operation of the large bell has been partly compensated by a system of automatic variable firing on the stoves. Such a system is of particular value on a plant without gas-holders.

(f) *Automatic Variable Firing on Blast-Furnace Stoves*

The original arrangement for stoves firing was to maintain a constant pressure in the stoves header by means of a pressure regulator, and thus keep the rate of firing constant. When there was a drop in the main gas pressure owing to reduced make of gas or increased demands of interworks units, the regulator at the stoves would open up to maintain the same pressure in the stoves header, and this would result in a further drop in the main gas pressure.

Appreciable improvement in gas utilization and control can be obtained by making use of the considerable heat-storage capacity of the stoves over short periods by using variable firing. An automatic system was therefore devised which gives a high rate of firing when the gas pressure is near bleeding point or gas is being bled, and a low rate of firing when the gas pressure drops below a certain value. The system has also the further function of rapidly reducing the gas flow to the stoves when there is a sudden drop in gas pressure, such as occurs when the large bell is lowered to drop the charge. In this way a steadier gas pressure is available for interworks units and boilers, and the control of gas flow at the boilers

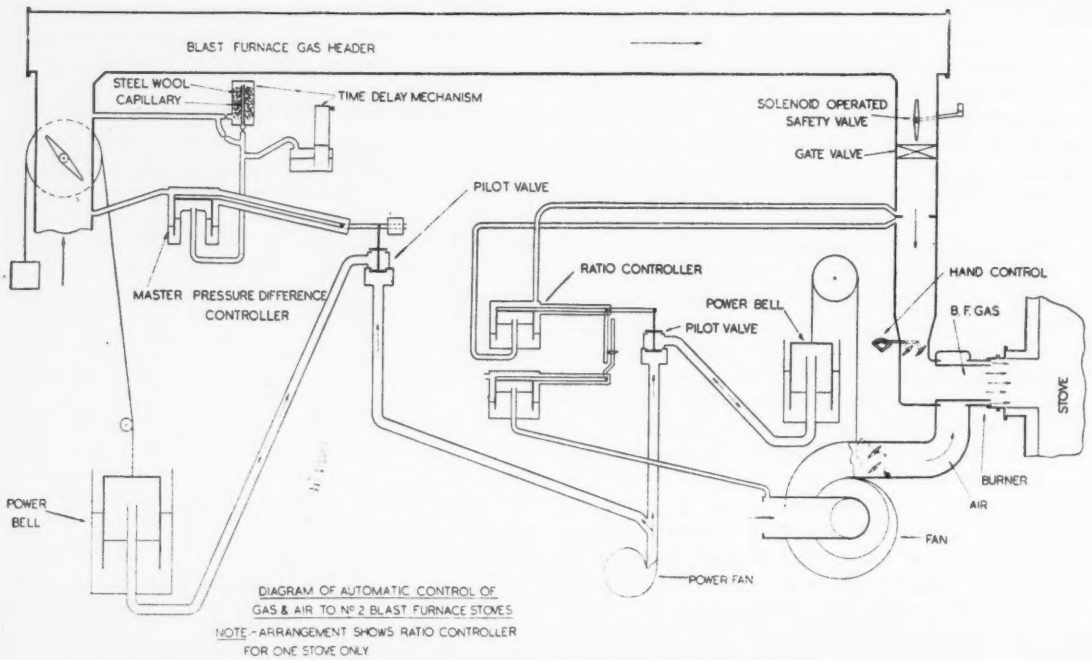


FIG. 7—Automatic system for variable firing of stoves

is greatly facilitated. The total gas flow to the stoves of No. 2 furnace can be varied from 100,000 to 1,300,000 cu. ft./hr., this being equivalent to a boiler load of from 8000 to 90,000 lb. of steam per hour. Appreciable quantities of blast-furnace gas are also pushed into the stoves instead of being bled to atmosphere, and this results in savings of gas.

A diagram of the system as applied to No. 2 blast-furnace is shown in Fig. 7. This system comprises the master regulator controlling the gas flow to all stoves and the individual air/gas ratio controller on each stove. The master controller is a differential pressure controller which maintains the pressure in the stoves main at 13 in. W.G. below the pressure in the interworks main. The normal pressure in the interworks main is 18 in. W.G., and the corresponding normal pressure in the stoves-header main is 5 in. W.G. With this pressure each stove can take a normal flow of about 600,000 cu. ft. of gas per hour. Should the gas pressure increase to the bleeding pressure of 23 in. W.G., the pressure in the stoves header will rise to 10 in. W.G. and the flow on the stove would increase by 42%, that is to 850,000 cu. ft./hr. On the other hand, if the gas pressure drops from the normal value of 18 in. W.G. to 13 in. W.G. the gas flow to the stoves is reduced to a trickle sufficient to keep the burners alight. In this way the rate of flow may be varied by about 800,000 cu. ft./hr. per stove, or about 1,300,000 cu. ft./hr. for two stoves under average conditions.

The master controller consists of a mercury-sealed bell which is subjected to the pressures before and after the regulating valve (1). This bell actuates the pilot valve (2), which causes the power bell to open or close the main regulating valve so as to maintain a constant pressure differential. This differential can be varied by shifting the weight (3) on the balance beam. A time-delay device is introduced in the low-pressure lead of the master controller. The purpose of this device is to obtain quicker response to pressure fluctuations on the high-pressure side, so that a pressure drop equivalent to only a few inches water gauge will, if it takes place rapidly, cause the gas to the stoves to be cut back to a very small flow and thus prevent a further drop in the main gas pressure. As mentioned above, the lowering of the large bell and the dumping of the charge cause such a momentary drop, and the stoves regulator responds quickly enough partly to compensate for this drop in gas supply.

Typical charts of the main blast-furnace-gas pressure before and after the installation of automatic variable firing are shown in Fig. 8. It can be seen that a considerable improvement has been effected in stabilizing the main blast-furnace-gas pressure. A further improvement would also be obtained by extending the system to the stoves of No. 1 blast-furnace.

To obtain satisfactory and efficient operation, the ratio controllers on the individual stoves have to operate quickly. This has been fully realized in

practice, and the air flow follows the gas with practically no time-lag. Stoves efficiencies were appreciably higher after the introduction of variable firing with the ratio controllers. No trouble has been experienced in maintaining the required blast temperature under this method of heating. The blast temperature ranges between 1100 and 1200° F.

During the war, the long delivery times for imported control equipment would have delayed execution of various projects discussed in this paper, and the control equipment described was designed and built at the works.

A pilot valve (Fig. 9) was evolved, which gives a high speed of regulation when the pressure of flow is a considerable amount off the desired point, and as that point is approached the speed of regulation is progressively reduced, so avoiding over-regulation or hunting.

In Fig. 9*a* the pilot valve is shown in mid-position when the controller is in or near balance. The gaps between the valve discs and valve body are then at their minimum, and the power bell which moves the main regulating valve (*see* Figs. 7, 22, and 23) is pneumatically locked in position but is ready to move at slow speed to compensate for any minor changes in pressure. A relatively large change in pressure or flow will result in a large out-of-balance force on the controller, which in turn will cause the gap for the passage of air through the pilot valve to open wide, as shown in Fig. 9*b*, and this will cause fast operation of the power bell. The power bells, which consist of bells sealed in oil, are somewhat bulky, but they need little or no maintenance and are very reliable. Ratio flow controllers are designed for 2·5 in. W.G. differential at maximum flow, and they respond to differentials down to 0·01 in. W.G., giving a wide range of accurate control. The spindles pass through frictionless seals in the form of synthetic-rubber torsion tubes, all the knife edges or pivots being external. Air for the controllers is supplied by a fan with a flat-pressure characteristic, as a relatively constant pressure is required for accurate control.

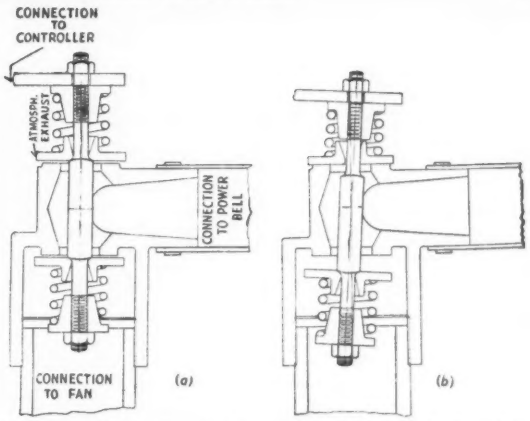


FIG. 9—Pilot valve (*a*) in mid-position and (*b*) with controller off balance, giving high speed of regulation

The air for all the controllers is supplied at 150 cu. ft./min. and 18 in. W.G., by a blower driven by a ¾-h.p. motor. The air is cleaned in a viscous filter before passing through the fan, and a small amount of air is allowed to leak into the controller cabins, to exclude outside dust.

(g) *Automatic Bleeder Control*

Surplus blast-furnace gas is bled through a 24-in. and a 30-in. bleeder, both bleeders being provided with orifice meters. Accurate and quick control is required, as the flow to be bled varies from 60,000 to 3,000,000 cu. ft./hr. Fast operation is also necessary, to cope with sudden rise in pressure owing to slipping of the furnace burden. Originally the bleeder valves were operated by an electric controller, but this was unreliable and slow in operation, and speeding-up resulted only in hunting on small flows.

The new regulator, which employs the same type of pilot valve as already described for the stoves installation, does the full travel in only

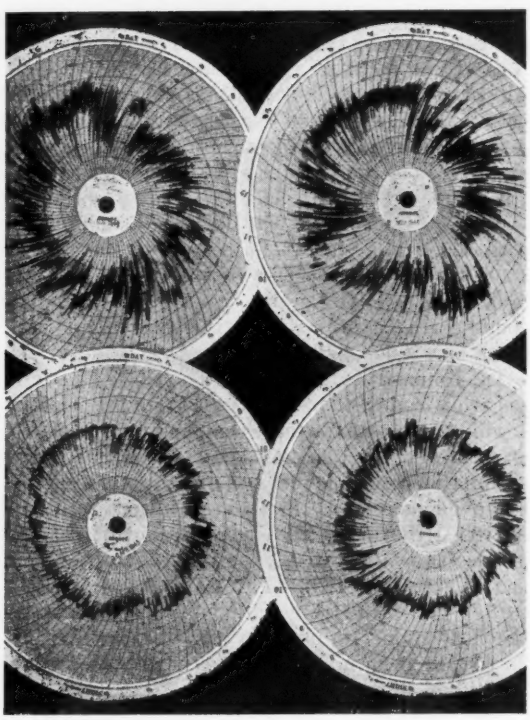


FIG. 8—Main blast-furnace-gas pressure before (top charts) and after (bottom charts) installation of automatic variable firing

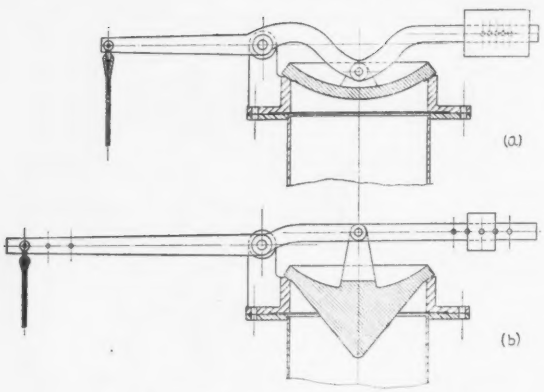


FIG. 10—Old and new bleeder valves

8–10 sec. and operates without hunting, down to the smallest flows. To obtain the above high speeds of operation and to cope with the large weights of the valves to be moved (1500 lb.), the pilot valve has a 2-in. dia. connection and the power bell is 4 ft. in dia. It is to be noted that there are no glands, pistons, or diaphragms, so that absolutely reliable and maintenance-free operation has been obtained.

The original 30-in. mushroom valve used to chatter badly at times when opening, setting-up severe vibrations in the mains. When the new regulator was installed a heavier valve was provided, with its centre of gravity lower in relation to point of suspension. The construction of the old and new valves is shown in Fig. 10.

IV—Effects of Fuel Redistribution on Open-Hearth Operation

Sufficient coke-oven gas was released by the conversion of the first eight soaking pits in 1942 to relieve the acute shortage of coke-oven gas at the open-hearth plant and also provide some surplus, which was burned mixed with producer gas at the open-hearth plant or at the coke-oven boilers. Further quantities of coke-oven gas were later released after conversion of the remaining eight top-fired soaking pits. Such surplus coke-oven gas could have been used in conjunction with blast-furnace gas and producer gas as tri-gas at the open-hearth furnaces ; this, however, would not have materially reduced the disadvantages of producer-fired furnaces, and proposals were submitted and experiments started early in 1943 to increase the heat input by the use of more coke-oven gas on the tar-fired furnaces, thus reducing the proportion of tar. By converting the 10-in. mill furnace to blast-furnace gas firing and reducing the coke-oven-gas consumption of small units to a minimum—in addition to the savings effected at the soaking pits—it would be possible to convert at least two open-hearth furnaces from producer-gas to tar/coke-oven-gas firing. The benefits which were derived from this can be gauged by the following comparisons :

(1) The fuel consumption on the producer-fired furnaces, averaged over the six months ending November 1942, was equivalent to 9,430,000 B.Th.U./ton of steel, and the average fuel consumption on the tar-fired furnaces for the period 1942 to 1944, calculated on the same basis, was 4,240,000 B.Th.U., a saving of 5,190,000 B.Th.U./ton of steel.

(2) The maintenance and repairs required on the tar-fired furnaces were only 53% of those required on the producer-fired furnaces.

All the above fuel rates are overall figures and include the heating-up fuels. Other benefits, which are difficult to evaluate, are increased production, greater availability, and reduced labour.

The first step in the experiments was to instal two additional coke-oven-gas burners alongside the central burner. The maximum gas flow per furnace was stepped up from 80,000 cu. ft./hr. to 120,000 cu. ft./hr., and the rate of tar firing was reduced. Only the central coke-oven-gas burner had a tar atomizer. These initial experiments were successful, and the conversion of the 10-in. mill furnace to blast-furnace-gas firing was approved so that further coke-oven gas could be released for usage at the open-hearth plant. Experiments with various types of tar atomizers and the disposition and number of the burners are still being conducted.

From the point of view of fuel utilization it is important to have burners and furnaces which permit a wide range of tar flow, so that the tar rate can be reduced and tar stored when there is an increase in the amount of coke-oven gas available, and *vice versa*. The fuel-storage value of 1 cu. ft. of tar is 1,200,000 B.Th.U., as compared with 500 B.Th.U./cu. ft. for coke-oven gas, that is 2,400 times greater. One of the 10,000-gal. rail tanks used at Port Kembla to transport tar to the open-hearth plant contains the equivalent fuel value of a 4,000,000-cu. ft. coke-oven-gas-holder.

The tonnage of steel produced on tar/coke-oven-gas firing from 1942 to 1945 is shown in Fig. 11, and it will be interesting to note that, in spite of a sharp drop in the total make of coke-oven gas, steel production from this fuel was not only maintained but even increased, this being a direct result of the redistribution of coke-oven gas shown in Fig. 2. As also shown in Fig. 11, the tar consumption per ton of steel was reduced from 13·0 gal. in 1942 to 7·8 gal. in 1945, corresponding to a drop in the heat input supplied by tar of from 50% to 36%. Much lower figures have been obtained on individual furnaces.

The fuel rates are calculated on the gross calorific value of the fuels, and, as there is a much greater difference between the net and the gross calorific value of coke-oven gas (523 B.Th.U. gross,

470 B.Th.U. net, per cubic foot) than in the case of tar (196,000 B.Th.U. gross, 192,000 B.Th.U. net), an increase in fuel rate based on gross calorific values will result when the proportion of coke-oven gas is increased, other things being equal. This is partly responsible for the increase in fuel rate indicated in Table II, which shows the overall-performance figures of three 220–240-ton tar/coke-oven-gas fired furnaces from 1941 to 1945. The greater availability of coke-oven gas has made it possible to increase the heat input, which has risen by 43% over the period stated. The production rate also increased, by 20%.

In the quest for more coke-oven gas it was decided to convert the coke-oven-gas-fired ladle dryers to blast-furnace-gas firing. Two such dryers were in use, consuming up to 15,000 cu. ft. of coke-oven gas per hour. A blast-furnace-gas-fired ladle dryer was installed in 1943, and this has not only achieved the desired saving in coke-oven gas but has also improved the drying of the ladles. Only one blast-furnace-gas-fired dryer has been installed, and this can cope with present requirements.

The set-up of the blast-furnace-gas-fired ladle dryer is shown in Fig. 12. The ladle is placed horizontally against a strongly built wall made of girders protected by brick lining. The burner is designed to give intimate mixing of gas and air, together with a high flame velocity so that the flame strikes the bottom of the ladle. The velocity

TABLE II—*Performance Figures of Three 220–240-Ton Tar/Coke-Oven-Gas Fired Furnaces*

	1941	1942	1943	1944	1945
Fuel consumption, millions of B.Th.U./ton of steel	3·71	3·94	4·14	4·25	4·42
Average heat input per furnace, millions of B.Th.U./hr. ...	54·9	61·1	61·5	65·9	78·6
Average production per furnace-operating hour, tons ...	14·75	15·50	14·80	15·43	17·80
Hot metal in charge, % ...	68·9	67·2	67·5	66·3	67·6

of the fuel gases at the burner mouth is 12 ft./sec. at N.T.P., and it is considered that a 30–40% increase in velocity above the present figure would result in further improvement in drying. A refractory-lined burner tunnel is provided to maintain ignition, and a small coke-oven-gas pilot is used for lighting-up. Air is supplied by a forced-draught fan, of 650 cu. ft./min. capacity against 4·8 in. W.G., driven by a 3-h.p. motor. Blast-furnace-gas consumption is about 50,000 cu. ft./hr., and the drying time varies from 2 to 5 hr. for a 150-ton ladle. The installation of this dryer has resulted in a saving of 60,000,000 cu. ft. of coke-oven gas per year, which allows of a further 7000 tons of steel being produced on the tar/coke-oven-gas fired furnaces per year.

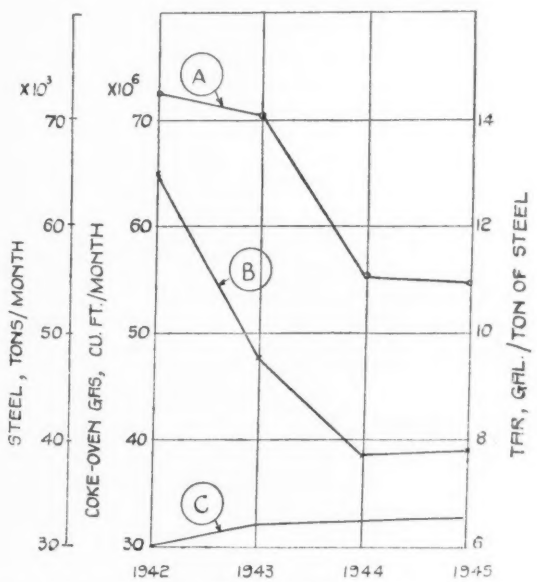


FIG. 11—Steel production on tar/coke-oven-gas firing, 1942–1946. Curve *A*, coke-oven-gas production; curve *B*, tar consumption; curve *C*, steel production on by-product fuels

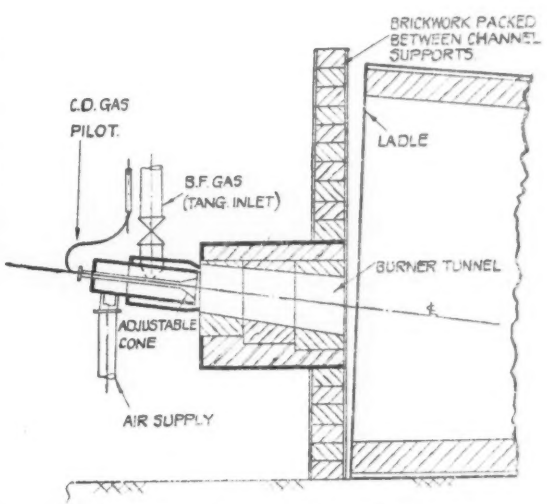


FIG. 12—Blast-furnace-gas-fired ladle dryer

V—Soaking Pits

(a) *Original Layout*

The soaking-pit installation comprised 16 top-fired pits built in 1931, and six modern regenerative pits constructed in 1938 and fired with coke-oven gas. These pits were all of the same size, each holding eight 4·4-ton ingots.

The top-fired pits used producer gas generated in hand-fed producers, supplemented by coke-oven gas. All these pits discharged into a common underground flue and each pit was originally fitted with a water-cooled damper, but, owing to the high exit temperatures, it was difficult to keep these valves in good condition, and after a short while they were discarded. The flue gases passed through two metallic regenerative air heaters; these units required frequent major overhauls and heavy maintenance, and their efficiency was low, due primarily to heavy internal leakage. Owing to high pressure drops on both the air and the gas sides, the power consumption was high, amounting to about 350 h.p. for the two units. The control of air and gas to each pit was mere guesswork, and the fuel consumption was excessive and the overall heating costs twice as high as on the new regenerative pits.

In 1941 a proposal for an experimental conversion of one of the 16 top-fired pits was approved. It provided for the installation of air and gas metallic recuperators, so that blast-furnace gas with some coke-oven gas could be used. The main body of the pit was retained, but new burners were installed. The operation of the pit proved satisfactory, and, with a view to relieving the serious shortage of coke-oven gas, the conversion of the remaining 15 pits was proceeded with at a rapid rate. While the first group to be converted (pits 9 to 16) operates on an average blast-furnace-gas/coke-oven-gas ratio of 40 to 1, some improvements were introduced in the second group so that these could be fired on straight blast-furnace gas.

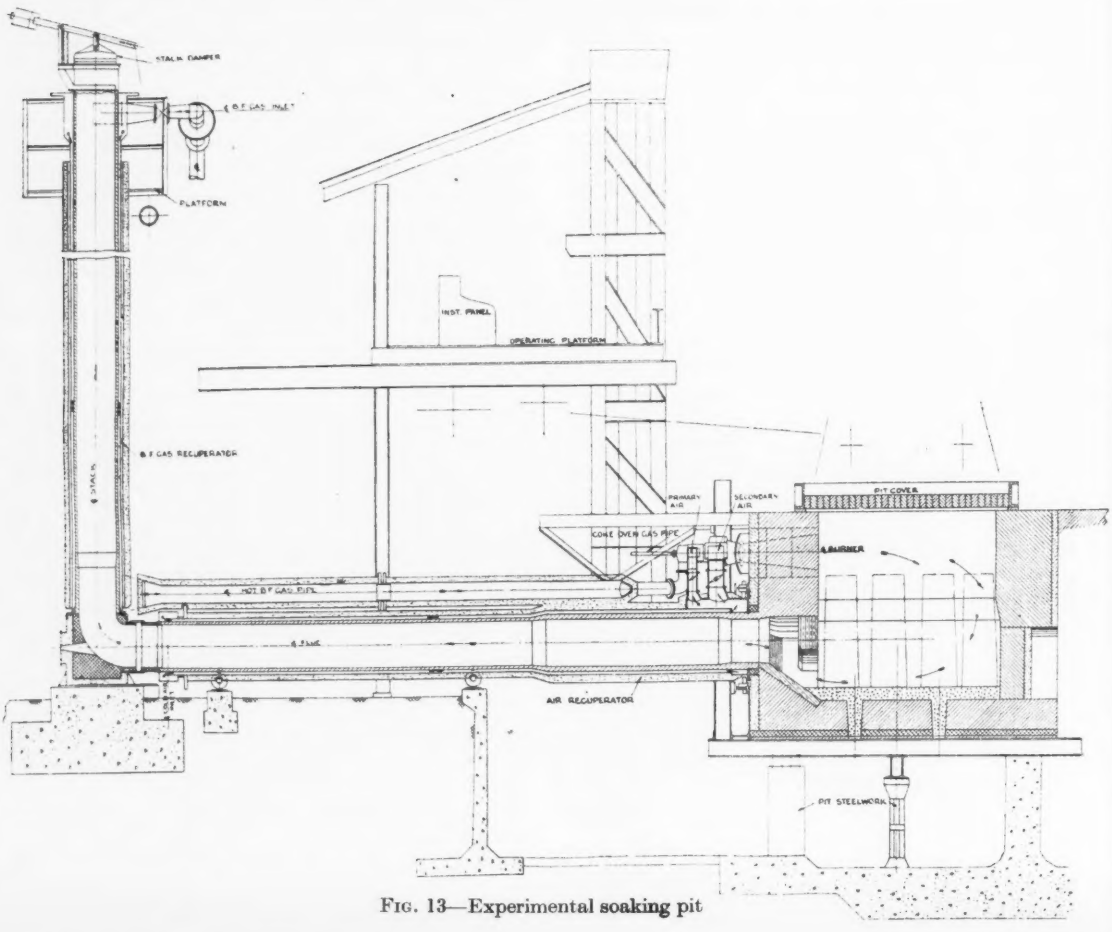


FIG. 13—Experimental soaking pit

(b) *Experimental Soaking Pit*

The experimental blast-furnace-gas/coke-oven-gas fired soaking pit is shown in Fig. 13. The two burners are located over the top of the ingots, and the flue gases are withdrawn at the bottom of the same side. The flue gases first pass through the horizontal air recuperator and then through the vertical blast-furnace-gas recuperator.

Combustion air is supplied by a fan delivering 1800 cu. ft./min. against 7 in. W.G. The air is heated to about 800° F., and the flow is controlled by two butterfly valves located at the burners. These two valves are mechanically interlocked so that the primary-air valve is nearly full open before the secondary-air valve starts to open. In this way a relatively high air velocity is maintained, to promote recirculation of the flue gases within the pit at low flows.

The air recuperator is made entirely of mild steel. It consists of a large inner tube, 35 ft. long, lined with refractory 4½ in. thick at the hot end, reducing to 2 in. at the cold end. This tube is closely surrounded by an outer tube, forming an annular space through which the air passes at high velocities. A metallic expansion joint is provided for the differential expansion between the two shells. The pressure drop on the air side is 3·6 in. W.G. at full load, and the pressure at the burner box is 2·4 in. W.G. Certain improvements were made in the recuperators for the second group of pits, the recuperators being only half as long and giving air preheats up to 1100° F.

The blast-furnace gas is heated in a vertical recuperator of similar construction, which also acts as the stack. The heating section is 35 ft. long and the blast-furnace gas is heated to 600° F. The pressure drop on the blast-furnace-gas side is 1 in. W.G. It is interesting to note that, in spite of the considerable amount of dust and sludge which is carried in the gas, no cleaning of the blast-furnace-gas recuperator has been necessary for periods of up to 2 years.

The pit pressure is controlled by means of a lid-type damper placed on top of the stack. This is a casting with a brick lining, and it gives a very good seal and can be operated with ease. No automatic controls of any kind were provided on this pit, but both the air and the gas are metered, and the flows can be adjusted from levers located in the instrument panel.

The proportion of coke-oven gas and blast-furnace gas can be varied as required. Normal flows when heating cold steel are 6000 cu. ft./hr. of coke-oven gas and 50,000 cu. ft./hr. of blast-furnace gas (136 B.Th.U./cu. ft.), the amount of coke-oven gas being gradually reduced as the steel gets hot and soaking is done on straight blast-furnace gas. A chart on the instrument board shows the quantities of air required for various flows of coke-oven and blast-furnace gas.

Performance figures are given in Table III. These show that, even with moderate air and gas preheats, economical operation on a gas mixture of low calorific value is possible. The heating time for eight cold ingots is 10–11 hr.

Typical weekly performance figures, inclusive of lighting-up fuel are :

	Week Ending 16/5/42	Week Ending 9/5/42
Steel charged, tons ...	819	653
Cold steel, %	15·1	33·7
Steel/pit/shift/ton ...	39·0	31·1
Fuel consumption, B.Th.U./ton	830,000	1,200,000

In addition to cold steel, there is a fair proportion of chilled steel.

(c) *Blast-Furnace-Gas Fired Ten-Ingot Pits*

In the conversion of the second group of eight pits (pits 1 to 8), the length of the pits was increased so that they could hold ten ingots as compared with eight. This required only minor alterations to brickwork and cover. A further extension to 12 ingots could be carried out if required, at a later date. The increased holding capacity is of great advantage, particularly in a plant having large-capacity steel furnaces with

TABLE III—*Heating Times and Fuel Consumption in Experimental Pit*

Number of Ingots or Slabs	Condition	Time from Tap to Charge. Hr. Min.	Time Ready. Hr. Min.	Total Time in Pit. Hr. Min.	Fuel Consumption, B.Th.U./ton	Calorific Value of Mixed Gas, B.Th.U./cu. ft.	Weight of Charge, tons
Ingots							
7	Hot	1 30	1 25	2 25	350,000	136	30·8
8	,,	1 46	1 20	2 00	215,000	170	35·2
8	,,	1 05	2 05	3 40	240,000	170	35·2
8	,,	1 47	1 30	4 35	575,000	154	35·2
5	Chilled	3 08	3 50	5 10	920,000	140	29·0
Slabs							
8	Chilled	3 17	5 10	7 05	960,000	143	35·2
8	Cold	...	10 10	10 35	1,630,000	131	35·2
8	,,	...	10 50	12 25	2,050,000	155	35·2

heats of 250 tons. Instead of building the eight pits in one continuous group, they were divided into two separate units, which gives a stronger construction. As the live-roll table of the blooming mill is very close to this group of pits the space available for recuperators was very restricted, but in spite of this a very satisfactory layout which provided for ample ventilation and access around the pits was obtained.

The general layout of one of the pits is shown in Fig. 14. The pit is 13 ft.3 in. long by 6 ft. 6 in. wide by 10 ft. 3 in. deep, and can hold ten 21 × 25 × 75-in. ingots or six 20 × 38 × 78-in. slabs. The whole of the brick structure is steel-encased and insulated. The basement is well ventilated and lighted.

These pits also have two burners, but the size of the burner tunnel has been reduced and its shape changed from circular to rectangular as compared to the first group of converted pits. This has resulted in a stronger construction of the pit wall. The pits are constructed of standard firebricks, with the exception of a strip 2 ft. high above the bottom, which is built of magnesite bricks or pipes filled with magnesite. Where the tops of the ingots lean against the side walls, the brickwork has worn away to a depth of 6 in. or more in three years.

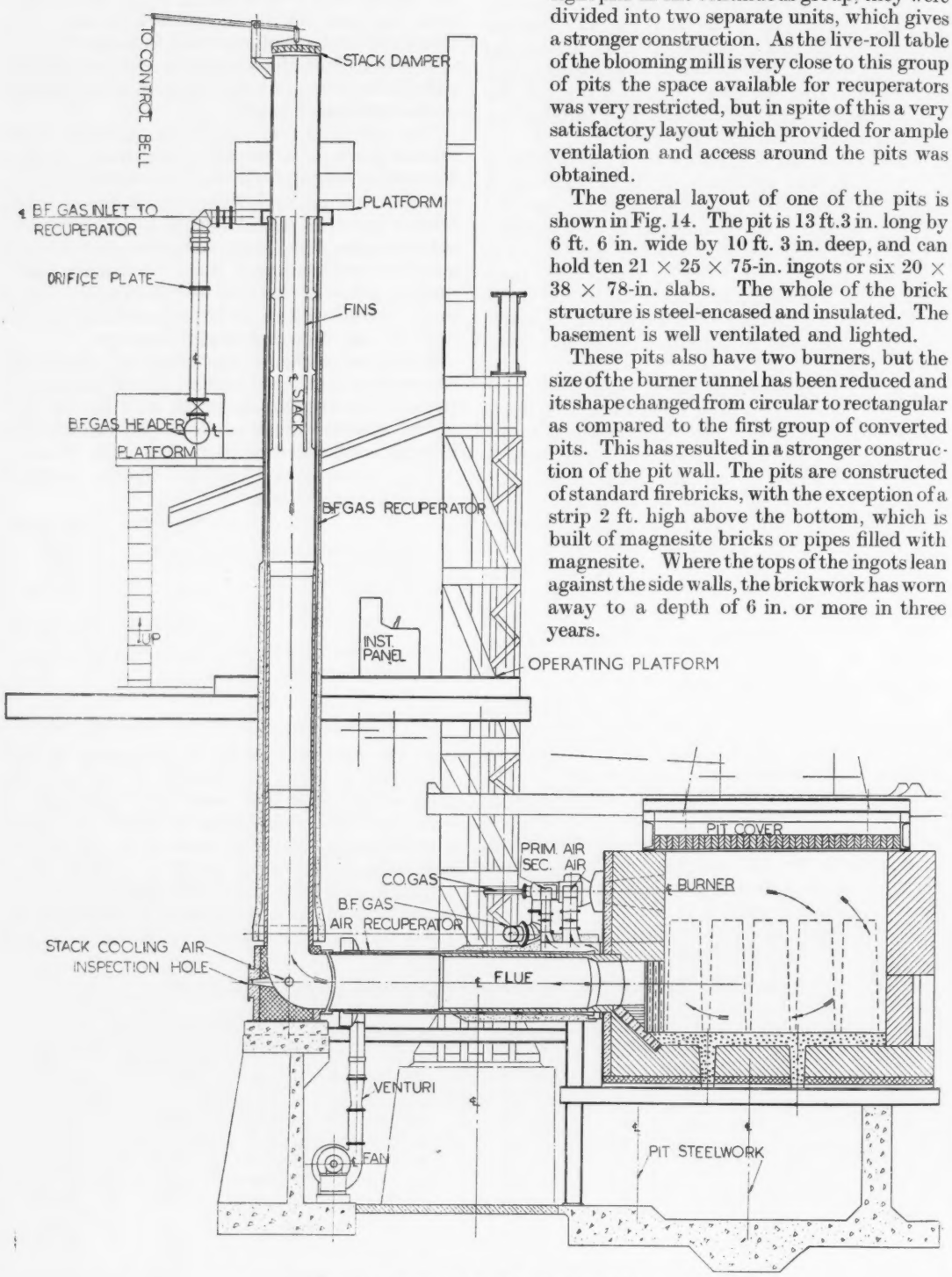


FIG. 14—General layout of ten-ingot pit

The air recuperator (Fig. 15) heats the air to 800–1100° F. The hot end of the recuperator is made of heat-resisting steel containing 25% of chromium and 20% of nickel, and the cold end of mild steel. The inner metallic shell is 16 ft. long by 3 ft. 3 in. dia. and has a refractory lining $1\frac{1}{2}$ in. thick, reducing to $\frac{3}{4}$ in. at the cold end. The heat-transfer rates of these recuperators are very high as compared to those of the conventional type. On the flue-gas side heat transfer is obtained by gas radiation of the H_2O and CO_2 in the flue gases with practically no pressure drop of the flue gases. On the air side high rates of heat transfer are obtained by using small gaps for the air, high velocities, and from the re-radiation effect of the inner to the outer shell.

An interesting feature is that the recuperator has a self-cooling characteristic which prevents overheating at low flows or when the air supply is interrupted. From Fig. 14 it will be seen that only the hot end of the recuperator is lagged outside, the cold end being left bare. Under normal flow conditions, the unlagged section is relatively cool and external radiation losses small. However, when the flow of air through the recuperator is reduced or completely interrupted, the temperature of the unlagged cold end will rise and dissipate sufficient heat to the atmosphere to protect the recuperator against overheating. The hot end of the recuperator is also protected, although it is well lagged externally, because it can re-radiate internally to the cooler surface of the bare end.

The vertical blast-furnace-gas recuperator is 40 ft. long by 2 ft. 6 in. in. dia. and heats 80,000 cu. ft./hr. of blast-furnace gas to 900° F. The brick lining is 3 in. at the base, reducing to $\frac{1}{2}$ in. at the top. Both the inner and outer shell are made of mild steel, and, in spite of the high temperatures carried, no scaling is apparent after three years of operation. The longitudinal expansion of the inner shell is used to operate a cooling valve, which admits cold air at the base of the recuperator should its temperature increase above a certain value. This device is extremely simple and robust. No instruments or controllers are needed or used for the protection of the recuperators. The top of the blast-furnace-gas recuperators is shown in Fig. 16.

The pits are equipped with automatic furnace-pressure controllers which maintain a pressure of + 0·01 in. W.G. at pit-top level. They also have safety devices to shut off fuel when the air supply is interrupted, air/gas ratio controllers (pits 1 to 5), and automatic fuel shut-offs which operate when the door is lifted.

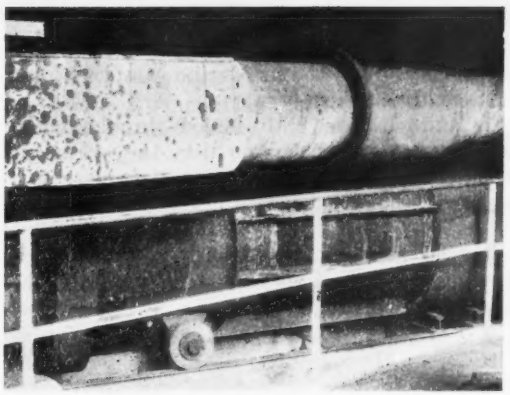


FIG. 15—View of horizontal air recuperator

The pits are well insulated, 6 in. at the bottom and $4\frac{1}{2}$ in. on the sides. The main heat losses are through the cover and the shoes of the cover, and some improvement is possible at these points. In the outlet flue a brick baffle prevents direct radiation from the hot pit to the cooler surface of the recuperator.

Several tests to determine heat losses were carried out with a pit full of hot steel, with the fuel turned off, the air fan shut down, and the stack damper closed. The temperature of the steel was measured through a sight hole in the side walls; this temperature dropped from 2460° F. to 2350° F. in 2 hr.

The bottoms are cleaned once a week by dumping the cinder through two large openings in the floor (*see* Fig. 14). The doors for these are controlled by levers in the basement. The amount of slag made is small, and coke breeze is used about twice a week for levelling the bottom.

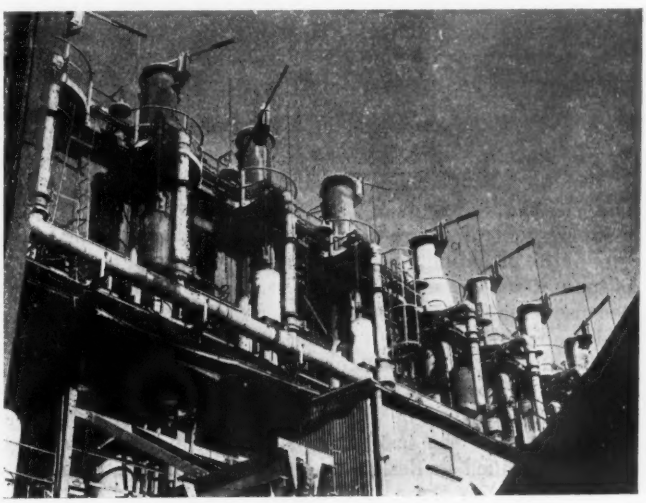


FIG. 16—Blast-furnace-gas recuperators

(d) *Combustion Conditions*

On several pits test holes were provided so that the temperature of the ingots and samples of flue gases could be taken.

Air and gas are both forced through small apertures in the burners so that they can mix intimately, and combustion is complete before the gases enter the furnace, with practically no excess air.

Flue-gas samples, taken with a water-cooled sampling tube 6 in. from the burner mouth in the pit, analysed as follows :

CO_2	25·8%	26·6%
CO	0·5%	...
O_2	...	0·2%

By using high outlet velocities of the flame, a considerable amount of recirculation can be obtained if the path of the flame is unobstructed. The long tunnel-like space between the cover and the ingot tops provides ideal conditions for entrainment of flue gases by the incoming flame, producing uniform furnace atmosphere, even temperatures, and improved heat transfer by convection, as the average length of gas travel is considerable. The outlet temperatures of the gases are close to the final steel temperature.

These features, in conjunction with automatic fuel/air ratio and pit-pressure and temperature controllers, should result in almost ideal conditions for good heating, with a minimum of scale losses. In this connection the air-tight construction of the all-welded recuperator is of great advantage, because accurate air/gas ratios can be maintained over the full range, owing to the absence of air leaks. The availability of high pressures at the burners results in compact burner design and the best possible conditions for mixing and recirculation of the gases within the furnace.

Accurate determination of scale losses at the soaking pits is very difficult. However, some tests were carried out at the continuous heating furnace, and these will be discussed later.

(e) *Operating Experience with High-Temperature Recuperators*

The air recuperators handle flue gases at temperatures in excess of 2500° F., and no instruments or controllers are used to limit the temperature of the incoming flue gases. In the recuperators of pits 9 to 15, some trouble was experienced because of mechanical weakness in the shell design and the falling of some of the bricks in the lining of the horizontal recuperators. The change-over point to different diameters (*see* Fig. 13) in the shell is also a source of weakness. The horizontal recuperators of the last group of eight pits are much simplified in design and are more rugged. Maintenance on these is confined to occasional replacement of the brick lining, and the plates show no deterioration after three years of service. The total maintenance cost of the air and blast-furnace-gas recuperators of these pits, in the third year of operation, is 1% of the total heating cost.

(f) *Performance*

The fuel rate of the pits depends largely on the output and on the proportion of cold and chilled steel charged. Only for five months did the converted pits operate on a basis of 18 mill shifts per week. For the remaining period the mill worked only 12 shifts per week. The fuel-consumption rates, the outputs, and the percentages of cold steel are shown in Table IV. The average temperature of the steel drawn is 2400° F. Owing to a relatively small heat input in relation to the weight of the charge in the ten-ingot pits, the heating time from cold for a full charge is rather long, varying between 12 and 16 hr., according to the gas supply.

TABLE IV—*Performance Figures for Soaking Pit, Firing Straight Blast-Furnace Gas of 90–95 B.Th.U./cu. ft. Calorific Value*

	18 Shifts per Week		12 Shifts per Week
Output of steel, tons/pit/week	920	680	490
Cold steel, %	3·0	19·0	19·6
Fuel consumption,* B.Th.U./ton of steel	620,000	950,000	1,300,000

* Including week-ends and holidays.

On a test with cold ingots (80% of the full charge) and blast-furnace gas enriched to 101 B.Th.U./cu. ft., the heating time was 9 hr. 30 min. The heating times could be shortened by increasing the heat input and also by increasing the preheats of air and gas, as indicated in the next sub-section.

The annual output obtainable per pit, when heating 19% of cold steel and a similar quantity of chilled steel, is 30,000–40,000 tons/year. Considering the small space required (40 × 42 ft. for a group of four pits, including recuperators for air and gas), and the low calorific value of the fuel (about 90 B.Th.U./cu. ft.), the general performance is very satisfactory.

(g) *Design Considerations*

A proposal for a blast-furnace-gas-fired soaking pit with air and gas both preheated to 1250° F. is shown in Fig. 17. Such a pit can be designed to take up to 16 ingots, and a very high production and holding capacity can be accommodated in a very small space. The construction of the pit is simple and robust. The performance of such a pit would be much superior to that of the pit illustrated in Fig. 14.

In short pits (up to 12 ft. long) at least two burners should be used, and in longer pits (12–20 ft. long), one burner. From the point of view of gas mixing and cost one burner is preferable to two.

Sufficient space should be allowed between the ingots so that they can be charged and drawn without disturbing the adjoining ingots and so that the ingot which is being handled can be placed in position without twisting or turning. If this can be done the life of the pit brickwork will be increased appreciably.

When heating cold steel it is advisable to load the pit to only 80%, or less, of full capacity, so that heat can be transferred from the top of the pit to the bottom, by radiation. This will result in even heating.

The flue gases are withdrawn through a short horizontal flue and flow upwards through the air recuperators. The air recuperator is made of heat-resisting steel and is suspended from the top, and has no internal refractory lining. The air enters at the bottom in parallel flow with the flue gases. This results in very high rates of heat transfer at the cold end, dropping rapidly towards the hot end, so that the temperature differential between the air and the heating surface is low at the hot end. It will be noted that the recuperator is unlagged at the cold end, so that when the air flow is reduced or interrupted this part of the recuperator can radiate outwardly at a high rate to prevent the building-up of excessive temperatures.

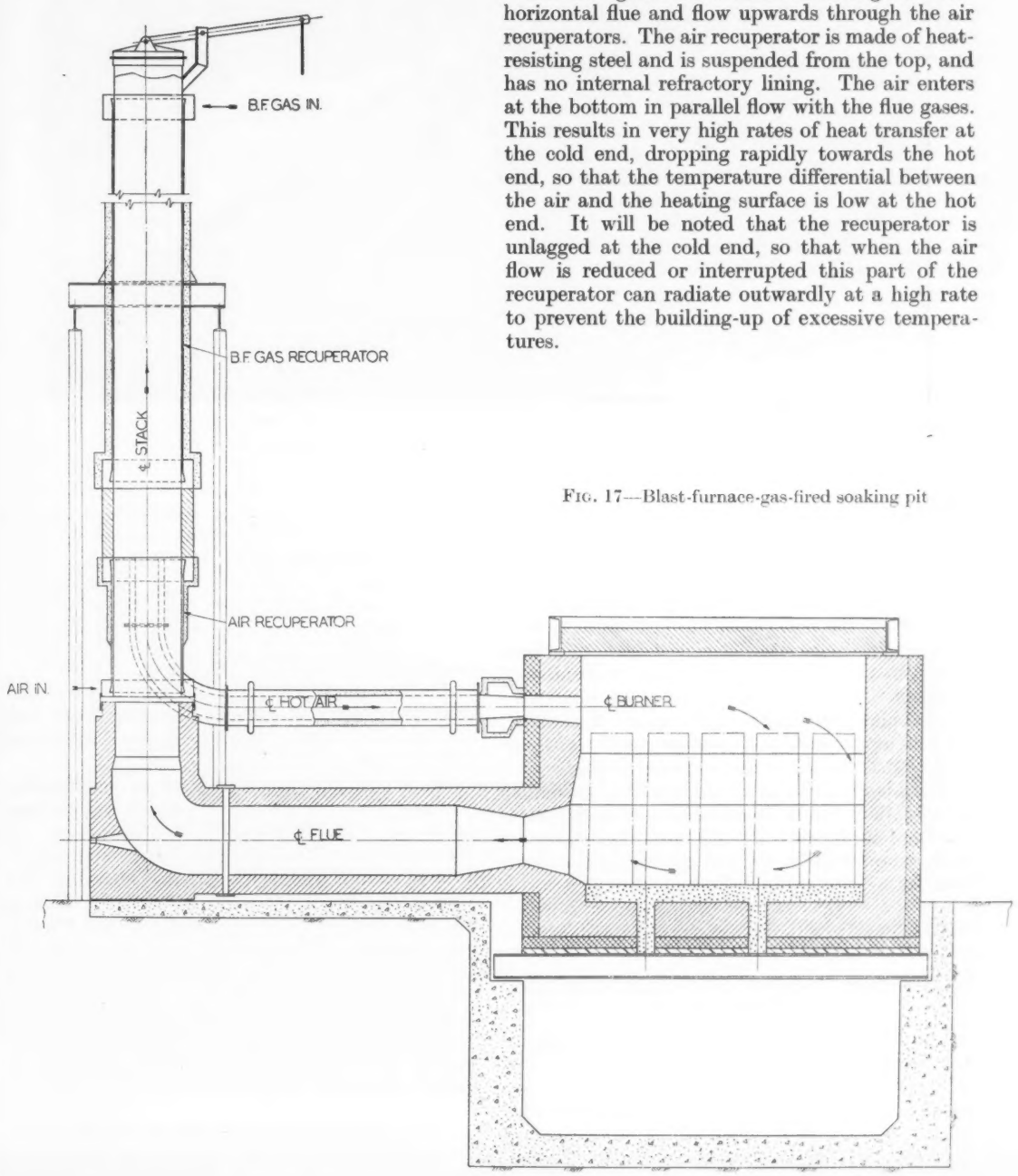


FIG. 17—Blast-furnace-gas-fired soaking pit

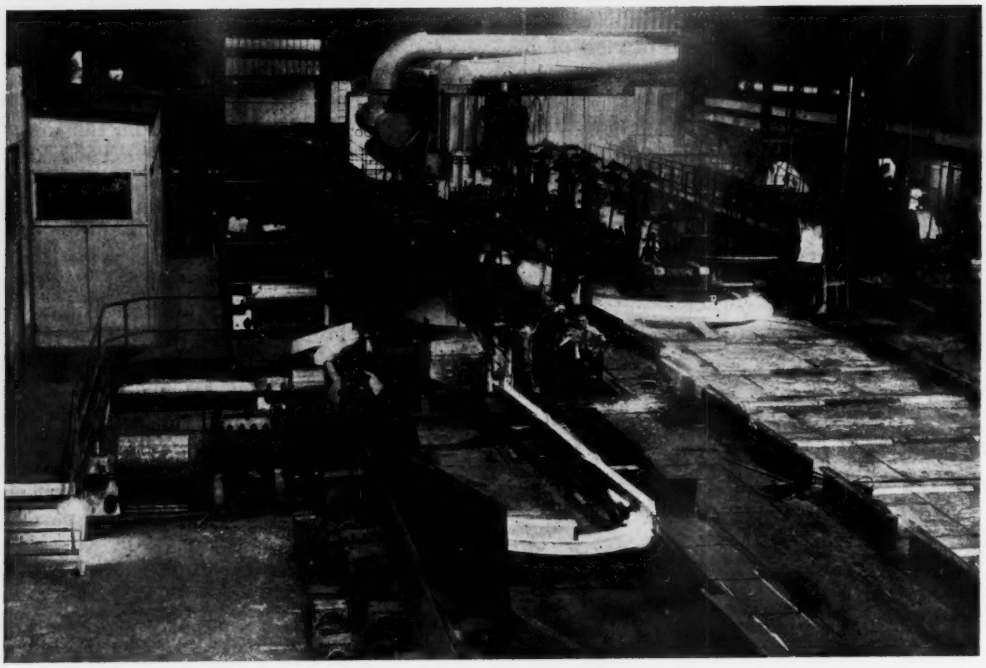


FIG. 18—General view of 10-in. mill and furnace

The heat transfer on the flue-gas side is obtained by direct gas radiation and from radiation of the brick-lined inlet and outlet flues. The heat transfer by convection is only small at this stage.

With the high exit temperatures of 2300–2500° F. of the flue gases, the heat-transfer rate on the air recuperator is very high. The unit shown in Fig. 17 would have a heat-transfer rate of about 20,000 B.Th.U./sq. ft./hr. On an experimental unit operating with flue gases at 3000° F. inlet temperature, heat-transfer rates of over 30,000 B.Th.U./sq. ft./hr. were obtained.

The blast-furnace-gas recuperator is of similar construction, but it is suspended at about two-thirds of its height. At the upper end fins and baffles are provided, to increase the rate of heat transfer by convection.

VI—TEN-INCH MILL CONTINUOUS HEATING FURNACE

(a) *Operating Experience with Original Coke-Oven-Gas-Fired Furnace*

The 10-in. mill (Fig. 18) rolls a wide variety of merchant products, amounting in all to 760 different sizes and shapes. The maximum production is obtained on $\frac{3}{4}$-in. rounds, the record output for one shift being 375 tons of finished products, or 49·5 tons/hr. of steel heated. Sometimes the mill maintains outputs of 55 tons/hr. for periods of 2–3 hr. The approximate proportion of products rolled is as follows :

Flats	53·1%
Rounds	38·4%
Squares	4·4%
Hexagons	3·7%
Channels, tapers, etc. ...	0·4%

The heating furnace was built in 1938 for coke-oven-gas firing and can handle billets 30 ft. long and $1\frac{3}{4}$–4 in. square, as well as slabs measuring 6 in. × 4 in.

In the original layout the air for combustion was first drawn over the roof—which was enclosed with steel plating—and then pushed by the forced-draught fan through the recuperators located under the skids at the charging end. Owing to the varying amount of air leakage through the preheater, as well as the varying temperature of the air at the metering orifice on the suction side of the fan, it was difficult to adjust the air flow. However, within a short time, many tubes failed, and little benefit was obtained from the recuperator, so that the whole unit was by-passed by removing tubes in various sections of the recuperator.

(b) *Conversion to Blast-Furnace-Gas Firing*

The main purpose of converting the furnace to

blast-furnace-gas firing was to release coke-oven gas and divert it to the open-hearth furnaces, as already explained. Of the 450,000 cu. ft./hr. of coke-oven gas supplied by the ovens for inter-works use, as much as 140,000 cu. ft./hr., or about 31% of the total, were required at times for the 10-in. mill furnace. Owing to the nature of rolling-mill operation, with frequent roll changes and other mill delays, the fuel demand of this unit varies widely, suddenly, and frequently, and therefore the efficient usage of coke-oven gas in other units is detrimentally affected if no gas-holder is existing. Particularly with a fuel like coke-oven gas, it is necessary to reduce the fuel almost immediately when the mill stops rolling, otherwise overheating of the billets on the hearth would occur.

On the other hand, the quantity of blast-furnace gas required by the 10-in. mill furnace represents but 7% of the amount of blast-furnace gas produced, so that changes in gas consumption of this unit will not materially affect other major consumers such as boilers and stoves. Blast-furnace gas gives also a much milder heat, and the fuel need not be immediately reduced when the mill stops.

The conversion had to be carried out without lengthy interruption of mill operation. Recuperators, mains, fans, and regulators were installed while the furnace was in normal operation, and the actual connecting-up and alteration to outlet flues was carried out in about six days, while the furnace itself was being repaired.

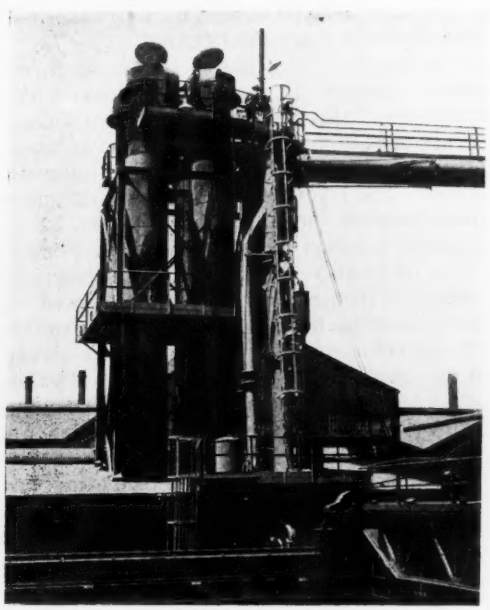


FIG. 19—General view of stack recuperators, 10-in. mill furnace

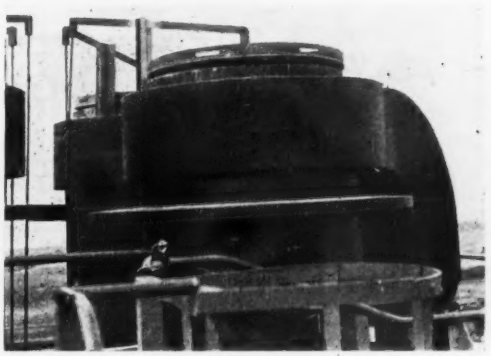


FIG. 20—Stack dampers

The recuperative system consists of four stack-type recuperators (*see* Fig. 19), two for blast-furnace gas and two for air. In spite of the very large volume of flue gases handled (over 1,000,000 cu. ft./hr. at 60° F.), the ground space taken by all the recuperators is only 13 × 13 ft.

In the conversion, the plating over the furnace roof was removed and insulation 3 in. thick placed directly on the suspended bricks. No alterations were carried out to the roof lines. The old recuperator tubes and flues were removed, and a well-insulated flue of 36-sq. ft. area was constructed to take the flue gases to the recuperators, which are only 8 ft. away from the back end of the furnace.

The two air recuperators are 3 ft. 6 in. in dia. and 65 ft. long. The flue gases enter the recuperator through a spiral, so that the gas column rotates as it moves upwards. The object of this is to improve the heat transfer by convection. Towards the upper or cold end of the recuperator, baffles are provided which increase the heat transfer by convection without reducing the heat transfer by gas radiation. Fins, which vary in size according to position, are also provided.

The two blast-furnace-gas recuperators are 4 ft. in dia. and 65 ft. long. The recuperators are suspended at about two-thirds of their height and are free to expand upwards as well as downwards. The cold-air inlet and the blast-furnace-gas inlet have metallic expansion joints, whereas the outlets have joints of the water-seal type. These are so built that the actual water seal is well protected from the heat of the hot air and gas. The lower end of the recuperators is made of heat-resisting steel containing 20% of nickel and 25% of chromium, and the top section is made of mild steel.

Each recuperator is provided with a light lid-type damper which has an asbestos sheet lining (*see* Fig. 20). These dampers give a very tight seal, so that the furnace is still red hot when it is

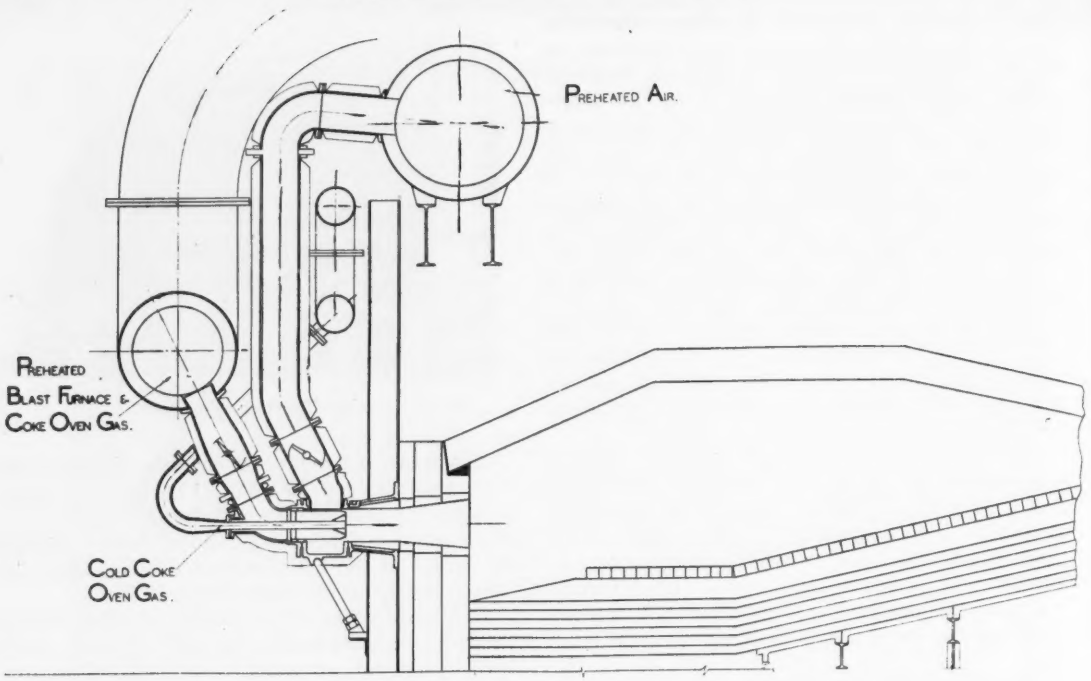


FIG. 21—Combination burners for blast-furnace gas and coke-oven gas

lit up 18 hr. after taking the fuel off at week-ends. Keeping the furnace warm during shut-downs has also a beneficial effect on the life of the furnace brickwork. No adjustment or repairs have been required over a two-years period. These four dampers are all operated together by a single automatic furnace-pressure controller. A compensating device is provided, which is actuated by the expansion of the recuperators in such a way that if one recuperator expands more than the others the stack damper closes and reduces the flow of the flue gases. In this way the proportioning of flue gases between the blast-furnace-gas recuperator and the air recuperator is automatically adjusted to take care of changes in the mixture of the fuel, which varies from straight blast-furnace gas to straight coke-oven gas.

The modified burners for burning blast-furnace gas and coke-oven gas straight or mixed are shown in Fig. 21. The old outer casings with tangential air inlet were retained and a heat-resisting inner tube inserted for the blast-furnace gas. Coke-oven gas, when fired mixed with blast-furnace gas, is introduced into the blast-furnace-gas upstream of the recuperator, but when it is used straight, *i.e.*, without blast-furnace gas, it is introduced through a small central tube. This tube carries a cone which brings the blast-furnace gas into close contact with the air to give intimate mixing and high pyrometric efficiency of the flame. On the other hand, the cold coke-oven gas is fired in a single solid jet at high velocity, and the mixing with the air is delayed so that burning takes place further down in the burner tunnel.

Air is supplied by a fan of 13,500-cu. ft./min. capacity against 18 in. W.G., driven by a variable-speed slip-ring motor. As two different fuels are used in varying mixtures, the automatic control of the air/fuel ratio presented an interesting problem. The layout of the controls (except the furnace pressure control) is shown in Fig. 22.

A simple solution was obtained by dividing the air flow into two separate streams as shown, one of which is controlled in accordance with the blast-furnace-gas flow and the other in accordance with the coke-oven-gas flow. The two streams join up again into a single stream before passing through the recuperators. The method of control is self-evident from the diagram. When only blast-furnace gas is used, the flow of air required for this fuel is controlled by the regulating valve (*B*), which responds to the blast-furnace-gas/air ratio controller. The regulating valve (*C*) for the coke-oven-gas/air mixture is closed. When coke-oven gas is used, regulating valve (*C*), controlled by the coke-oven-gas ratio controller, will provide the amount of air required to burn the coke-oven gas. In this way the correct amount of air is

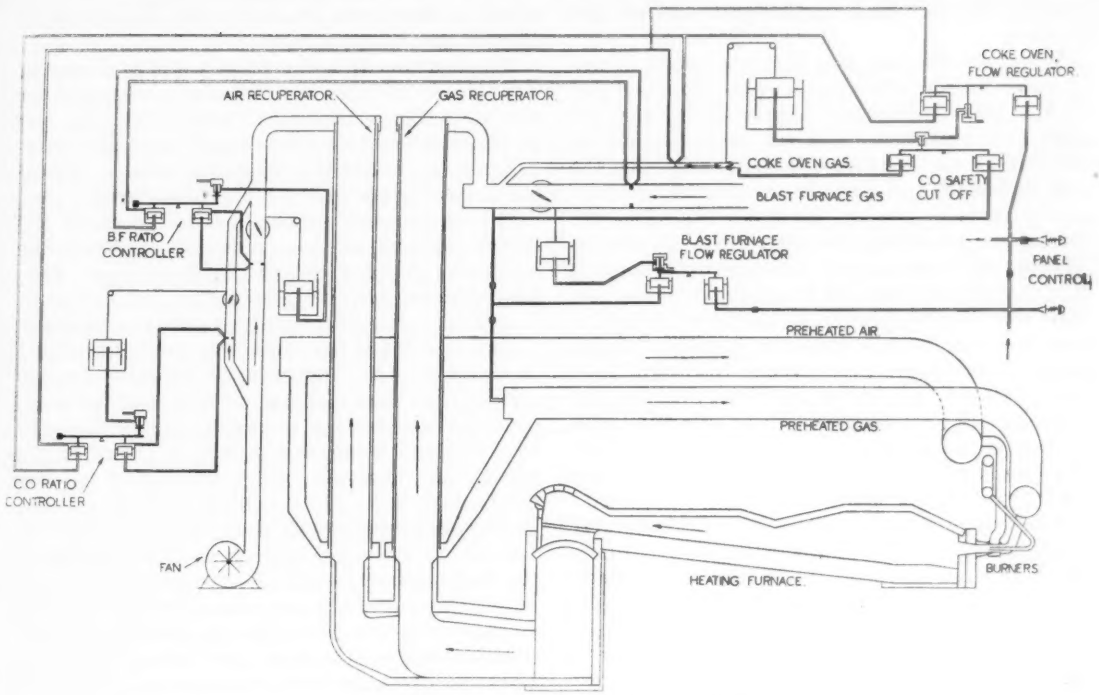


FIG. 22—Layout of automatic controllers

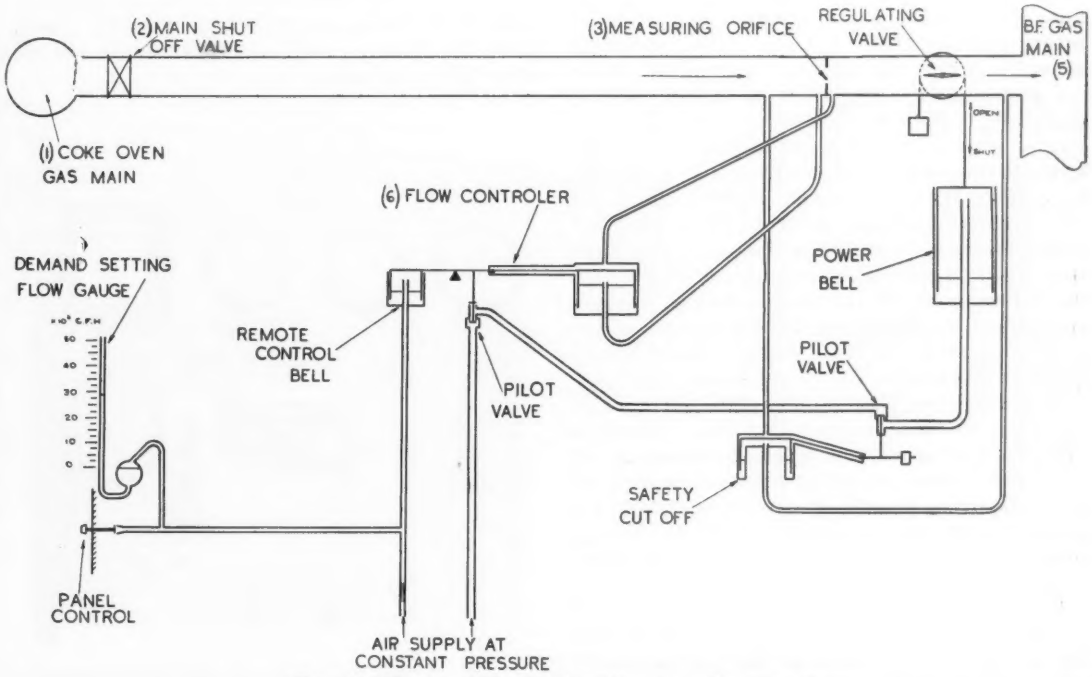


FIG. 23—Remote fuel-control system for coke-oven gas

provided for any blast-furnace-gas/coke-oven-gas mixture.

When the furnace was first converted it was operated for some time on straight coke-oven gas, as the blast-furnace-gas supply main was not completed until later. The coke-oven-gas flow to the furnace was controlled by hand only, and the flow varied up and down in accordance with the gas pressure. Previous to the conversion, the increase in gas during coke-oven reversals used to smother the furnace, with consequent wastage of fuel and slowing-down of heating. With the new ratio controller the air follows the gas immediately, and best combustion efficiency is maintained in spite of fluctuating gas pressure and flow. In a plant without a gas-holder, operation on a variable pressure will be more economical, as it will result in less bleeding of the coke-oven gas, but the consuming units must be equipped with efficient air/fuel ratio controllers.

The remote fuel-control system for coke-oven gas is shown in Fig. 23. Coke-oven gas flows from the coke-oven-gas main (1) to the blast-furnace-gas main (5) and is metered by the orifice (3). The differential from this orifice acts on the bell of the flow controller (6). This controller has also a smaller bell, subjected to air pressure, which can be controlled by a small leak-off valve on the instrument board. Each pressure under the remote-control bell will give a definite flow. The operator therefore turns the control knob until the demand-setting flow gauge shows the required flow. This gauge is a simple manometer, and the setting requires about 2–3 sec. The automatic controller brings the flow to the required value and maintains it irrespective of changes in the coke-oven- or blast-furnace-gas pressure. A similar control is provided for blast-furnace gas. This makes it very easy to use this furnace as a regulating unit for the coke-oven-gas supply. When the coke-oven-gas pressure drops below a predetermined pressure the operator cuts this fuel back and increases the blast-furnace-gas flow. On the other hand, if the coke-oven-gas pressure approaches bleeding point the coke-oven-gas flow to the furnace is increased, and the blast-furnace-gas flow decreased.

It will be noted that a safety cut-off is provided for the coke-oven gas (*see* Fig. 23). This is a differential-pressure bell which actuates an air relay and causes the power bell to drop and cut the coke-oven gas off when the coke-oven-gas pressure is equal or less than the blast-furnace-gas pressure. This is to prevent backflow of blast-furnace gas into the coke-oven-gas system.

The controllers are so arranged that the fuel is automatically cut off when the air supply fails. No separate valve is used for the automatic cut-off, but this is done by the main regulating valve, which is always on the move and is unlikely to stick in case of emergency.

The instrument and control panel is shown in Fig. 24. It includes a multipoint manometer for the air and gas pressures before and after the recuperators, and the blast-furnace-gas/coke-oven-gas pressure before the regulating valves. Above the finger-tip controls for the blast-furnace gas/coke-oven-gas flow are the flow indicators for the demand setting, as already described. Recorders are also provided for the coke-oven-gas flow, blast-furnace gas, air temperature, gas temperature, flue-gas temperature, and steel temperature.

In the centre of the panel there are four inclined flow gauges, which indicate the blast-furnace-gas flow and the corresponding air flow, and the coke-oven-gas flow and the corresponding air flow. In this way the heater can tell at a glance if the correct air flows are being maintained for any combination of the two fuels. These inclined gauges are provided with a slight slope at the bottom of the scale and a steep slope at the top of the scale, so that small flows can be read and adjustments made to the controllers with greater accuracy. These inclined flow gauges are brilliantly illuminated from the back, and the red liquid can be read with the greatest ease from a considerable distance. This is of great assistance to the heater. The inclined flow gauges are shown in Fig. 25.

The leads to the indicating instruments and those to the controller are quite separate. Most of the instrument troubles are due to blockage or leaks in the leads, particularly when dirty gases are used. With separate leads such faults can be more quickly located.

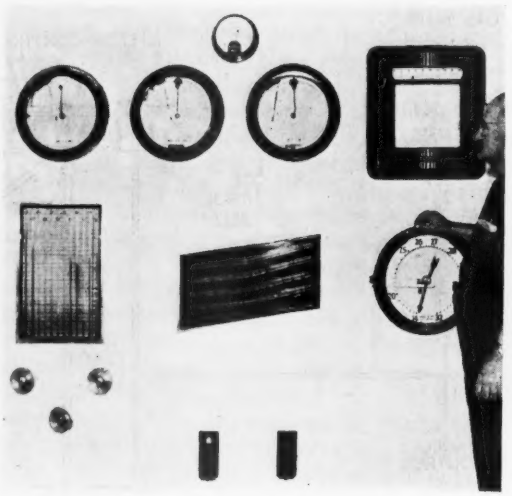


FIG. 24—Instrument board, 10-in. mill furnace

(c) *Operating Results*

The new recuperators were brought into service in July 1944, and during the two years' operation, no maintenance was necessary nor were delays caused by the recuperative system. The top part of the internal heating surface of the recuperators was brushed down after 15 months' service during a furnace overhaul period. At this point a whitish deposit about $\frac{1}{8}$ in. thick, originating from the blast-furnace gas, covered the surface and was easily brushed off. This was the only cleaning done in the two-year period.

The recuperators are all-welded, and perfect tightness has been maintained. This is of particular importance, as it permits accurate control of air/fuel ratios.

During the first six weeks the furnace operated on straight coke-oven gas, as the blast-furnace-gas main was not completed, and exceptionally good efficiency was obtained on this fuel.

An interesting feature of the use of preheated air was the reduction in the temperature of the flue gases leaving the furnace. The exit temperatures of the flue gases before and after installation of the recuperator for various rates of firing, indicating a reduction of about 100–200° F., are shown in Fig. 26. The back end of the furnace appeared much cooler, even by observation, and the heating was concentrated more towards the hearth. This in itself reduces radiation losses, and results in high efficiency even at low outputs. Whereas the flame was somewhat luminous before conversion, with the improved mixing and higher air preheat it was non-luminous. Heating conditions were quite as good, but considerably more care was required not to leave the fuel on too long during mill delays. Scale formation seemed to be less than with the slow, luminous flame.

The installation of recuperators, together with ratio controllers and the tight-fitting stack dampers, resulted in an overall fuel saving of 30%. This improvement is not only due to the direct reduction in waste-gas heat, but also to the reduction in furnace heat losses as a result of more concentrated heating, brought about indirectly by preheating the air and by accurate ratio control.

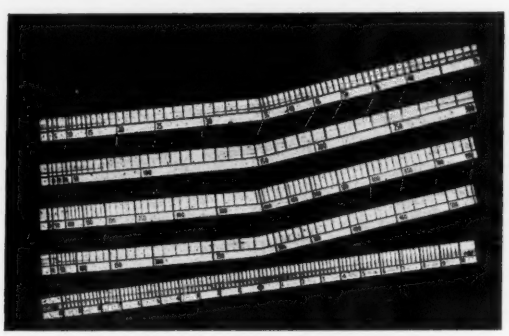


FIG. 25—Inclined flow gauges

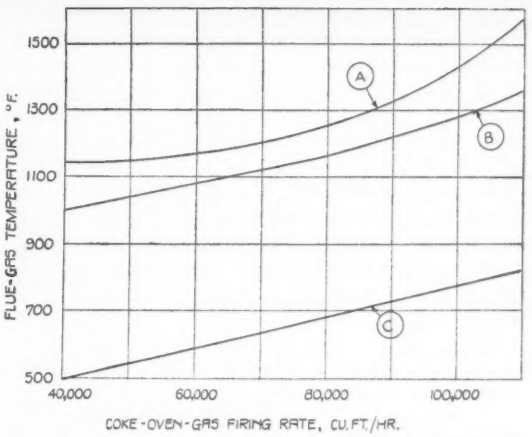


FIG. 26—Flue-gas temperatures on coke-oven-gas firing, before and after conversion. Curve *A*, exit flue-gas temperature without recuperation; curve *B*, exit flue-gas temperature with recuperation; curve *C*, final flue-gas temperature after recuperation

Air preheating resulted in a very substantial drop in the final flue-gas temperature. For an output of 35 tons/hr., about 110,000 cu. ft./hr. were required before conversion, and the final flue gas temperature for this firing rate was 1580° F. (*see* Fig. 26). After conversion the same rate of output required 77,000 cu. ft./hr., with a final exit temperature of only 670° F., a reduction of 910° F.

Performance figures with the new recuperators on straight cold-coke-oven gas are given below. The figures include fuel used on all delays, heating at week-ends (24-hr. shut-down period), and are based on the gross calorific value of the fuel. Efficiencies would be 10% higher if based on the net heating value.

Week Ending	Tonnage Heated	B.Th.U./ton	Efficiency
12/8/44	3033	1,364,000	57·6%
19/8/44	3955	1,383,000	56·8%
26/8/44	3274	1,385,000	56·7%
3/9/44	3644	1,288,000	61·3%

A test, carried out with the furnace operating continuously and without delays, gave the following results:

Average rate of steel heated	... 44 tons/hr.
Final flue-gas temperature	... 734° F.
Preheated-air temperature	... 5830° F.
Heat consumption (gross)...	... 1,105,000 B.Th.U./ton

Approximate Heat Balance

To steel	... 71%
Heat in waste gases ...	... 13·6%
Latent heat of H_2O ...	... 9·0%
Radiation losses	... 6·4%

On straight blast-furnace-gas firing the efficiency is lower, owing to the increased volume of the flue gases and the increased furnace heat losses. This has a particularly big effect on furnace efficiency on light loads. The furnace now operates practically all the time on straight blast-furnace gas, but for outputs of above 35 tons some coke-oven gas has to be used. The air and gas preheats vary between 650 and 900° F., according to load.

A 4-hr. test on the recuperative system, using a mixture of blast-furnace and coke-oven gas of 120 B.Th.U./cu. ft. calorific value, gave the following results :

Temperature of mixed gases after recuperators	858° F.
Temperature of air after recuperators	782° F.
Temperature of flue gases leaving furnace	1600° F.
Temperature of flue gases at stack exit	900° F.
Approximate total flue-gas volume	900,000 cu. ft./hr.
Net heat recovered by recuperators, as percentage of total heat of flue gases at furnace exit	47%
Radiation loss of recuperators' hot air and gas mains ...	3%

The pressure drop on the air recuperators is 7 in. W.G. at full flow, and on the blast-furnace-gas recuperator the pressure drop is 4 in. W.G.

In the proposal for conversion of the furnace it was estimated that the coke-oven-gas consumption would be reduced from the average of 52,000,000 cu. ft./month to 11,000,000 cu. ft./month. The actual consumption during the last few months has averaged less than 3,000,000 cu. ft./month.

The operating efficiency on straight blast-furnace gas is about 48% : monthly overall figures—including all delays and lighting-up—is about 1,750,000 B.Th.U./ton.

Since the conversion, a record week's production of 5,097 tons of finished products has been established for 18-shifts operation.

(d) *Quality of Heating*

The quality of heating obtained on blast-furnace-gas firing is better than with coke-oven gas. This is particularly true on the big sections, which are more thoroughly soaked owing to the earlier heating at the cold end of the furnace.

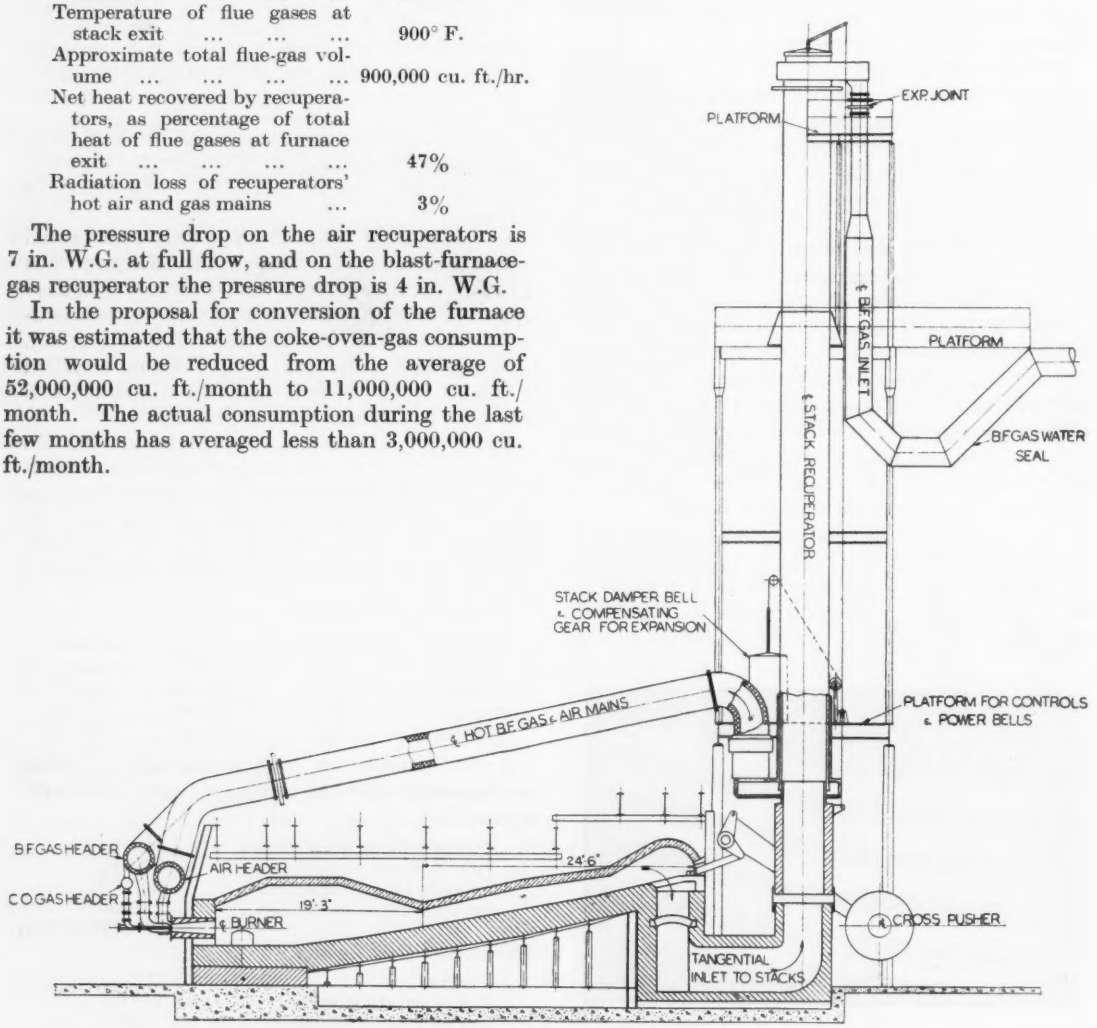


FIG. 27—Cross-section through new continuous heating furnace

Very even heating is obtained over the entire length of the billets.

Numerous accurate tests were carried out before and after conversion to determine the scale losses with coke-oven-gas firing and blast-furnace-gas firing. A large number of billets was weighed before charging to the furnace, and, after heating, the finished products and the crop ends were weighed on the same weighbridge. The difference was taken as furnace heating losses. The average scale losses for 2½-in.—3-in. billets were as follows :

	Scale Losses
On coke-oven-gas firing (average time of billets in furnace, 1 hr. 28 min.)	2·08%
On blast-furnace-gas firing (average time of billets in furnace, 1 hr. 35 min.)	0·78%
Saving in steel	1·30%

All the above tests were made under ordinary working conditions, no adjustments being made to the furnace for the purpose of the trials. The coke-oven gas contains 1 grain of hydrogen sulphide per cubic foot. In the case of coke-oven-gas firing no automatic controllers were installed, and, while some of the reduction in scale losses is no doubt due to the combined effects of accurate air/fuel ratio control and furnace-pressure control in the converted furnace, the saving is mainly a result of the different composition of the fuel gases. At this stage of the steelmaking process a ½% increase in steel yield is equivalent in value to the entire fuel cost for reheating. Another benefit, which is difficult to assess, is the increased life of the rolls owing to reduced scale.

The use of blast-furnace gas has also reduced hearth trouble. On coke-oven-gas firing it was necessary to clean out the hearth and make-up every week-end, which necessitated bringing in labour on Sundays. With blast-furnace-gas firing this is no longer necessary to the same extent.

Automatic control has greatly simplified the operation of the furnace, this in spite of the burning of two different fuels in various proportions.

No matter how reliable and elaborate the control equipment is, the best results will be obtained only if the operators have a broad understanding of the function of the equipment. A pamphlet was issued to operators, in which the reasons for the conversion to blast-furnace gas and coke-oven gas, and diagrams explaining automatic-control features and safe procedures for lighting-up and shutting-down, were set out. From the number of pamphlets issued it would appear that they found a much wider circle of interested readers than the operators immediately concerned with the furnace.

(e) *Furnace for New Rod-and-Strip Mill*

A rod-and-strip mill is being constructed at present, and the heating furnace will be of similar size and capacity to the 10-in. mill furnace already described.

A diagrammatic cross-section through the furnace, which can also handle billets 30 ft. long, is shown in Fig. 27. A few minor changes which will increase the furnace efficiency appreciably and improve its performance have been incorporated in the design. The burners are provided with a longer tunnel, and mixing has been improved by using a higher air pressure at the burner mouth and increased twirl. The number of burners has been reduced from 13 to 12.

The knuckle on the flue-gas outgoing side of the combustion chamber has been lowered from 21 in. to 18 in. The purpose of this is to reduce the loss of heat by radiation from the combustion chamber to the back end of the furnace. This is particularly desired on low outputs when firing blast-furnace gas.

With blast-furnace-gas firing the temperature of the charging end of the furnace is much higher than with coke-oven-gas firing. This results in heavy heat losses to the back-wall castings, which are bare on the existing furnace and have a total exposed area of nearly 50 sq. ft. This exposed area will be greatly reduced in the new furnace by providing a 3-in. lining of insulated concrete in the castings. Better and thicker insulation is being provided throughout, which will improve the efficiency at low outputs on blast-furnace-gas firing.

The skids at the charging end are water-cooled. On coke-oven-gas firing the heat losses from the skids are relatively small, owing to the low exit-gas temperatures. On blast-furnace-gas firing the heat losses mount up rapidly, owing to the high exit temperatures and the big increase in heat radiation from the flue under the skids. These losses amount to 3,500,000 B.Th.U./hr. on the existing furnace on high outputs and blast-furnace-gas firing, and they reduce the preheat of air and gas and the furnace efficiency. These losses will be smaller in the new furnace, owing to the smaller length of skids used. The possibility of using an air-cooled insulated skid is also being investigated ; the losses could also be completely eliminated by withdrawing the flue gases directly from the top, with elimination of flues below the furnace.

Two recuperators are again provided for blast-furnace-gas heating and two for air heating. The air recuperator is slightly larger, and with other various improvements preheats will be higher than on the present furnace.

VII—Gas Hazards

A Gas-Hazards Committee, composed of Blast-Furnace Executive Officers, the Blast-Furnace Superintendent, and the Combustion Engineer, from the Broken Hill Proprietary Company's steelworks at Newcastle and from the Australian Iron and Steel, Ltd., Port Kembla, deals with safe practice in all matters related to blast-furnace-gas usage. Rules and regulations have been issued which deal with all phases of blast-furnace operation involving gas hazards, such as blowing-in and blowing-out, lighting-up stoves, the gas-cleaning plant, purging of the mains, and repairs to gas mains and containers.

At present purging is done by steam. This is not satisfactory in long mains in cold and rainy weather, and consideration is now being given to the use of inert gases for this purpose.

With particular reference to the use of blast-furnace gas for heating steel, no mishaps have occurred in five years' operation. The use of blast-furnace gas preheated to 1000° F. or more does not present any special problems. The recuperators hold only a very small volume of gas, and there are no large chambers or dead pockets where explosive mixtures could be formed ; they can be purged through in less than 1 min.

An interesting feature of these installations is the main gas-regulating valve, which is also used as an automatic shut-off. In older installations a solenoid-operated safety cut-off was provided (*see* Fig. 7), which shuts the fuel off in case of fan failure. It is possible that such a valve, as it does not move normally, may fail to operate in case of emergency. In the new arrangement (Fig. 22) the regulating valve is also the safety cut-off valve. This valve is continuously on the move, and should it stick this would soon be apparent from faulty regulation. The main 30-in. dia. blast-furnace-gas valve on the 10-in. mill furnace operates on the same principle.

VIII—Results and Outlook

In assessing the gains derived from the use of blast-furnace gas for steel-heating at Port Kembla, as described in this paper, the cumulative effect on heat consumption from melting shop to finished product must be considered. The overall heat consumptions for periods before and after the conversions are given in Table V. All the rates shown are overall figures, and include all fuel used for drying and heating-up, and fuel used during holidays and other shut-downs. The monthly production in the second period has dropped considerably, and this adversely affects the overall heat consumption, yet the cumulative saving is 2,600,000 B.Th.U./ton of finished product (merchant bar). The results after full conversion for a month on a more comparable production rate are also shown, the saving in this case being 3,570,000 B.Th.U./ton of finished product. These figures include the equivalent heat contained in the coal required to supply steam to the gas producers, and for tar atomizing. The total saving in coal, which corresponds to 2,600,000 and 3,570,000 B.Th.U./ton of finished products, is in the range of 40,000 to 60,000 tons per year. As these savings were effected at a period of acute coal shortage, they have been of considerable assistance in maintaining steel production.

From Table V it will be noted that the heat-consumption rate in the melting shop has dropped from 6,150,000 B.Th.U./ton to 4,550,000 B.Th.U./ton. As previously stated, the fuel rate on the tar and coke-oven-gas fired furnaces has increased slightly with the change in the proportion of coke-oven gas in the fuel mixture, and the gain shown above is mainly due to the redistribution of fuels as a result of the blast-furnace-gas conversions, which resulted in the shutting-down of producer-fired furnaces.

Table V—*Cumulative Heat Consumption from and Inclusive of Melting Shop to Finished Products*

	Before Conversion	After Conversion	
Period :	3 years	1¼ years	1 month
Average ingot production, tons/month ...	54,153	38,926	46,135
Heat consumption, melting shop, millions of B.Th.U./ton of ingots	5·85* 6·15†	4·45* 4·55†	3·98* 4·08†
Heat consumption, soaking pits, millions of B.Th.U./ton of ingots	1·80‡ 1·83§	1·32‡ 1·32§	1·22‡ 1·22§
Heat consumption, 10-in. mill furnace mill, millions of B.Th.U./ton of billets	1·95	1·73	1·41
Cumulative heat consumption, millions of B.Th.U./ton of finished product	11·13§	8·53§	7·56§
Saving per ton of finished product, millions of B.Th.U.	...	2·60	3·57

* Excluding steam equivalent for gas producers and tar mill.
† Including steam equivalent for gas producers and tar mill.
‡ Excluding steam equivalent for gas-producers mill.
§ Including steam equivalent for gas-producers mill.

At the soaking pits an appreciable improvement in the overall fuel rate has been achieved. However, this gain has been reduced, owing to lower

production with the blooming mill operating only 12 shifts per week, as compared to 18 shifts previously, and, apart from the reduced throughput rate, this has also increased the proportion of cold and chilled steel charged. On the heating furnace the fuel rate is also better in the second period, in spite of the change-over from coke-oven gas to blast-furnace gas.

In addition to the reduction in cumulative heat consumption, the extended use of blast-furnace gas has resulted in a reduction of gas bleeding.

Increased yield owing to reduced scale losses has also an appreciable effect on the heat consumption. The overall fuel rate at Port Kembla, from the coking of the coal and the smelting of the iron ore to the finished product in the form of merchant bar or flats (including all power and heat in main and auxiliary units), is 39,000,000 B.Th.U. per ton of finished product, and a reduction of 1% in scale losses will result in a saving of about 350,000 B.Th.U./per ton of finished product.

The use of blast-furnace gas for heating steel has many advantages, not only in that it releases the rich coke-oven gas for steelmelting—which requires high temperatures—but also because it provides ideal conditions for good-quality heating.

Continuous heating furnaces originally designed for coke-oven gas can, in most cases, be converted quite satisfactorily to blast-furnace-gas firing, but the best results will be obtained on a furnace specially designed for blast-furnace-gas firing. Particular attention should be given to the reduction of bare-metal surfaces exposed to heat at the back end of the furnace, and the entire furnace structure should be well insulated.

On the soaking pits, thermal economy on blast-furnace-gas firing, particularly at calorific values of about 90 B.Th.U./cu. ft., can be obtained only if the gas is highly preheated, and the design shown in Fig. 15, with preheats of 1250° F. or higher, should give exceptionally low fuel consumption. The recuperator described may also open up new possibilities in the melting shop, as it can be used with flue gases heavily laden with suspended solids. Owing to its simple design, its costs of manufacture and installation are very low.

IX—Acknowledgments

The author would like to thank the General Manager of the Port Kembla Works, Mr. C. H. Hoskins, for permission to publish this paper. Thanks are also due to the Manager, Mr. A. S. Hoskins, the Chief Engineer, Mr. F. T. Merrett, and the Assistant Chief Engineer, Mr. F. Mathews, for their suggestions, and to Mr. E. Flynn, Mr. A. Taylor, and other members of the Combustion Department, for their assistance.

Historical Note No. 2

A Factory Doctor's Duties at an Ironworks in 1724*

By Dr. H. R. Schubert†

Ambrose Crowley has been called "the greatest ironmaster of the seventeenth century."[1] He started his working life as a blacksmith and became an alderman and sheriff of London, and was knighted; when he died, in 1713, he left a fortune of £200,000. He erected ironworks at Sunderland (County Durham) in 1682, and moved them to Swalwell and Winlaton, near Newcastle, in 1690. After his death he was succeeded by his son John.

Rules for the conduct of Crowley's business and for the behaviour of the workers employed in his factories were set out by Ambrose and John Crowley in a "Law Book," which is preserved among the manuscripts of the British Museum.[2] These regulations form a whole

[1] E.Lipson, "The Economic History of England," vol. 2, p. 178. London, 1943.

[2] British Museum, Add. MS. 34555. A précis of the regulations contained in the Law Book has been published by Rhys Jenkins in "Works Organization in the Seventeenth Century," *Transactions of the Newcomen Society*, 1925, vol. 4, pp. 95–101.

* Received 22nd February, 1947.

† University of Reading.

industrial and social code. The final item is concerned with the duties of a factory doctor.

In consideration of " the deplorable state of my honest and laborious workmen and their families when visited with sickness and other bodily infirmities," John Crowley appointed a factory doctor in 1724, and arranged to pay for all medicines needed. To avoid abuses by people " obtaining medicines on every light occasion," or by others " who have feigned themselves sick or disabled by bodily infirmities " and who sold the medicines obtained, he ordered that the following rules should be observed :

(1) He (*i.e.*, the doctor) is to be well skilled in physick and a professed chirurgeon (*i.e.*, a professional surgeon) and one that is of a sober life and conversation and not addicted so much to pleasure as to be withdrawn from a due attendance on his business.

(2) He is to give daily attendance in my factory and is not upon any pretence whatever to absent himself without leaving word at his shop where gone, or with the timekeeper at Winlaton, or at such other part of the factory as he shall depart from.

(3) He is not upon any pretence whatever to absent himself 48 hours without the Council's permission, and not then if the disorder of any person does absolutely require his attendance.

(4) When the health of the factory permits he may follow his practise anywhere within 10 miles distance.

(5) He is to observe that no persons are entitled to this relief (*i.e.*, medical treatment and medicine free of charge) but such officers, workmen, their wives and their servants that pay to the Poors Box and work for me and no other person.

(6) All workmens' and officers' children are to be relieved gratis, except such who have been abroad in service and returned home sick and infirm, or otherwise maimed in their limbs through any casulties or misfortunes.

(7) No hammerman that has not wrought a whole year or more in the factory is entitled to any relief gratis.

(8) Those that after having obtained medicines etc. for their own relief shall sell or otherwise dispose of them, shall for ever be excluded from the benefit of this relief gratis.

Rules 9 to 11 deal with penalties to be imposed on malefactors such as are mentioned in rule 8 ; on " due proof " they are to be fined 2*s*., the fine money going to " the informer."

(12) He (*i.e.*, the doctor) is not to compound medicines by any recipe brought him by any workman etc., but if they are to have the opinion of any Doctor of Physick, he is to go along with them or state their case to the most eminent or graduate physician in Newcastle or elsewhere.

(13) He is not to deliver any of my medicines or drugs to any person while able to follow his employment.

(14) If the doctor makes use of medicines and drugs entrusted to him by using them for his own private practise or for persons not entitled to get them, he will be liable to a fine of 5 shillings which are to be given to the informer.

(15) The doctor has to keep a journal on medicines and drugs given to patients.

The benefit of free medical treatment was restricted to officers (*i.e.*, staff) and workmen, and their families and servants, as far as they contributed to the Poor Box. This was a fund raised by a small tax on all earnings of the staff and the workmen. Excluded from the benefits were those workers who had contracted illness or who had suffered disablement while abroad. This exception was necessitated by the employment of numerous workers from Liège (Belgium) and the neighbouring districts of Germany. Hammermen were excluded for the first year of working, probably on account of the nature of their work making them more liable to " casulties or misfortunes."

The main idea of the Law Book was to keep the efficiency of the labour at the highest possible level. For this reason the employer would go to great length and would even permit a second medical opinion by an outside doctor. In contrast with this obvious liberalism is the incitement to informers to report contraventions committed by fellow-workers and also by the doctor against the rules of the Law Book. The idea of the informer being rewarded by money deducted from the earnings of his victims is abhorrent to modern thinking, but it was not unusual in the eighteenth century or earlier.

The Crowleys' Law Book has been exuberantly praised for its organization of work and for the benefits granted to the workers. However, many of these benefits, *e.g.*, the care of the ill and the disabled, were not new in the history of the English iron industry ; for instance, at the wireworks at Tintern (Monmouthshire), founded in 1565, pensions were paid to labourers unfit for work on account of old age or disablement. These pensions varied from 25 to 52*s*. per year, *i.e.*, from one-half to the full amount considered sufficient for means compatible with existence (2*s*. a week).[3]

[3] Public Record Office, Exchequer Depositions by Commission, Hilary 2 James I, No. 12.

The Application of Single Crystals to the Study of Tempered Martensite*

By Professor G. Kurdjumov† and L. Lyssak†

SYNOPSIS

The orientation relationships between martensite and austenite lattices in quenched steel enable the reflections (002) and (200), (020) of the martensite lattice to be obtained on separate films, using single-crystal specimens. Thus it becomes possible to measure the a *and* c *constants of the tetragonal lattice of martensite when the axial ratio* c : a *is small and its structure is inhomogeneous.*

In this paper the structure of tempered martensite has been investigated. The X-ray camera was provided with a special arrangement in order to increase the accuracy in measuring the lattice constants.

It has been established by direct measurements of the constants a *and* c *that martensite tempered at 125–150° C. has a tetragonal lattice with an axial ratio of about 1·012–1·013. The tetragonal lattice of tempered martensite has been observed after tempering at temperatures up to 250–300° C.*

Thus the product of the so-called "first transformation" in tempering or, otherwise, the tempered martensite, represents the partly decomposed solid solution of the carbon in α iron. After tempering at 150° C. a certain quantity of carbon, 0·3–0·5%, remains dissolved in the solid solution. It decreases as the tempering temperature rises and after tempering at temperatures above 300° C., less than 0·1% of carbon remains in the solution.

The kinetics of martensite decomposition has the character of the reaction of the first order.

INTRODUCTION

In discussing the results of the X-ray investigation of the structure of tempered steels, one of the authors[1] suggested that the decomposition of the α solid solution supersaturated by carbon (martensite) is not completed in the temperature range of the so-called first transformation in tempering (100–150° C.), but extends to temperatures as high as 300° C. According to this suggestion the diffuseness of the interference lines of steel tempered at 150°–300° C. depends to a certain degree on the inhomogeneous tetragonal structure having a small axial ratio of the tetragonal lattice. The presence of the inhomogeneous tetragonal structure is easily shown in steel tempered at 150° C. by the displacement of the (110) and (200) lines in different directions with respect to the corresponding α-iron lines.[1–4] At higher tempering temperatures (200–300° C.) no displacement was observed; this fact could be explained by the small difference in the size of the tetragonal lattice and that of the α-iron lattice. The absence of any effects of the first transformation during heating of quenched low-carbon steels and the analogy in the X-ray patterns of steels tempered at 150–300° C. and quenched low-carbon steels were considered as indirect confirmation of the above assumption.

In his paper[5] Hägg gave a detailed consideration and critique of the views of Japanese investigators on the nature of tempered martensite, and also came to the conclusion that "Cubic martensite (β martensite), accepted by Honda and others, does not seem to exist. The structural element described as cubic martensite probably consists of tetragonal martensite in which the tetragonal symmetry is not observable owing to low carbon content."

In investigating the structure of tempered martensite, Kurdjumov and Oslon[6] carried out the measurement of the breadth and displacement of different interference lines obtained in iron and chromium radiation for quenched 0·1–1·4%

* Received 8th August, 1946. The experiments described in this paper were carried out in the Metal-physics Laboratory of the State University in Dniepropetrovsk, in 1940–41.

† Academy of Sciences, Ukrainian S.S.R., Kiev.

carbon steels tempered at various temperatures. In the case of inhomogeneous tetragonal structure the breadth of the lines depends not only on the reflection angle, but also on the plane indices. The authors came to the conclusion that inhomogeneous tetragonal structure does not disappear in steel tempered above 150° C. up to 250–300° C.

To estimate the carbon content remaining in the solid solution after tempering at various temperatures, the breadth of the lines of tempered steel was compared with that of quenched 0·1–0·5% carbon steel. This method is liable to give somewhat exaggerated values, for in quenched steels with less than 0·6% of carbon the martensite partly decomposes during quenching. In this investigation the authors arrived at the following conclusions. In medium- and high-carbon steels tempered at 150–300° C. the decomposition rate of the α solid solution is very great at the initial moments of tempering, but rapidly decreases with time. The decomposition process reaches definite stages comparatively rapidly and then proceeds very slowly. To every tempering temperature there corresponds a certain carbon content remaining in the solution which changes very little by the further increase in tempering time.

This method has shown the carbon content remaining in the solution to be 0·4–0·5% after tempering at 150° C., 0·3–0·4% after tempering at 200° C., and 0·2–0·3% after tempering at 250° C.*

The martensite tempered below 300° C. thus represents a partly decomposed solid solution of carbon in α iron. The carbon-rich phase precipitated during the decomposition process cannot be detected by usual methods at tempering temperatures below 300° C. By using quenched single-crystal specimens, Arbusov and Kurdjumov could observe interferences of the phase precipitated on tempering in this temperature range.[7] It appeared that the precipitated phase was a carbide with a lattice different from that of cementite. The rhombic cementite lattice occurs at temperatures of 300–400° C. The composition and lattice of carbide of low-tempered steel have not been determined.

Measurements of the specific volume[8] and thermal effects[9] in tempering gave results in agreement with those obtained from the above-mentioned X-ray investigation.[6]

In the investigation of quenched austenite single crystals, owing to the regular orientation of martensite, Kurdjumov and Sachs[10] could observe, during tempering, the changes in the reflections of (002) apart from those of (200), and thus avoid the difficulties associated with the mergence of the doublets lines of the tetragonal lattice. After tempering for 15 min. at 100° C. near the (002) spot another spot appeared of which the position seemed to coincide with that of the (002) reflection of the α-iron lattice. As the tempering time was increased the intensity of the second spot increased at the expense of the first spot, the space between both spots becoming darker. On tempering for 2 hr. the first spot became hardly visible. These results were considered by the authors as the transition of the tetragonal lattice of martensite into the cubic lattice of α iron. After tempering for 2 hr. about 90% of the tetragonal lattice was bound to change into a cubic lattice.

This conclusion is in disagreement with the results obtained in investigating tempered polycrystalline specimens [1, 5, 6, 11]; it follows from these investigations that even more prolonged tempering at 100–150° C. does not bring about complete transition of the tetragonal lattice into a cubic lattice, while according to Kurdjumov and Oslon,[6] the tetragonal structure remains also at higher tempering temperatures. It should be noted that accurate measurements of the position of the interference spots could not be carried out in the investigations by Kurdjumov and Sachs[10] with the method applied in taking the X-ray photographs, and, as will be seen later, this led to the erroneous conclusion concerning the formation of the α-iron lattice in tempering at 100° C.

In the study of the structure of tempered martensite the authors made use of the possibility of obtaining separate reflections from (002) and (200), (020) by applying single crystals of austenite. Direct measurement of the lattice constants a and c showed that tempered martensite (below 300° C.) has a tetragonal lattice with a small axial ratio depending on the tempering temperature.

I—Material and Method

In this investigation cylindrical steel specimens 1 mm. in dia. and cut out of the same quenched austenite single crystal as used by Kurdjumov and Sachs[10] in 1930 for the determination of the lattice relationship in the austenite–martensite transformation, were used. Thus quenched steel (1·4% of carbon) was utilized which had been kept at room temperature for a period of 10 years.* As shown by the X-ray photographs, the degree of martensite decomposition after being kept at room temperature for 10 years was nearly

* These values refer to steels containing more than 0·4% of carbon.

* The experiments described in this paper were carried out in 1940.

the same as that achieved by tempering at 100° C. for ½–1 hr.

The specimens were cut out in such a manner that the axis of the cylinder was parallel to the [001] direction of the austenite lattice. The specimen was tempered at temperatures of 100° to 350° C. with an interval of 25° C., and then again at 650° C., being held for 1 hr. at each temperature. X-ray photographs were taken after each tempering.

Kurdjumov and Sachs showed that the poles of the (002) plane of the tetragonal lattice are located near the poles of the (100) plane of the austenite, and the poles of the (200) and (020) planes near the poles (110) of the austenite crystal (Figs. 1*a* and 1*b*). For certain positions of the specimen with respect to the incident X-ray beam the latter circumstance enables the reflections (002) and (200), (020) to be obtained on separate photographs.

Platinum was used as a standard substance whose (220) line lies near the reflections dealt with, on the side of the large angles. During the exposition the specimen was oscillated through a range of oscillation of 25° to make all the eight (002) poles and then all the eight (200), (020) poles take part in the reflection. The oscillation was necessary to obtain the correct position of the maximum spot intensities. Photographs were taken both with a usual Debye-Scherrer, 57·3-mm. dia. camera and with a distance of 81 mm. between the specimen and the film. The first were used for the photometry of the lines, and the second for the measurement of the lattice constants, a displacement of 0·1 mm. corresponding to a change of the constant by 1·9 XE.

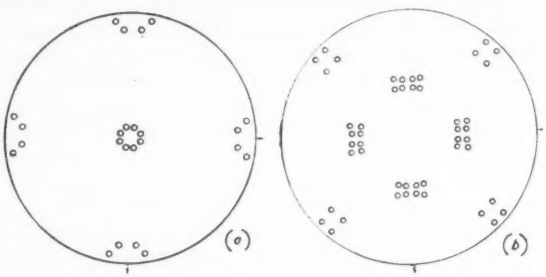


FIG. 1—Orientation of the poles of the martensite lattice with respect to the axes of the initial austenite crystal; (*a*) (002), and (*b*) (200), (002)

II—EXPERIMENTAL RESULTS

The photographs of the untempered specimen showed splitting of the (002) spots. Besides the spot corresponding to the reflection from the (002) plane of the quenched specimen, another spot appeared corresponding to the smaller value of the constant *c*, the intensity of the second spot being somewhat higher than that of the first spot. After tempering for 1 hr. at 100° C. the relative intensity of the second spot increased. Tempering at 125° C. caused the first spot to disappear (Fig. 2). Measuring the distances of the spots from the standard line showed that the spots due to the decomposition did not coincide with those on the (002) plane of the α-iron lattice, which is clearly seen when comparing the X-ray photographs obtained after tempering at 150° C. and 350° C. (Fig. 3*b*). Figure 3*a* represents the photographs of the reflections (002) and (200), (020) after tempering at 150° C. These photographs show that martensite tempered at 150° C. has a tetragonal lattice. The angles of reflection from the (002) and (200), (020) planes are clearly different. As seen from the X-ray photographs, the width of the spots exceeds the displacement; thus, when these reflections are photographed simultaneously, both kinds of spots cannot divide on rotation X-ray photographs nor on photographs of polycrystalline specimens, because both kinds of reflections are photographed simultaneously on one and the same film. In the authors' method both kinds of reflections are

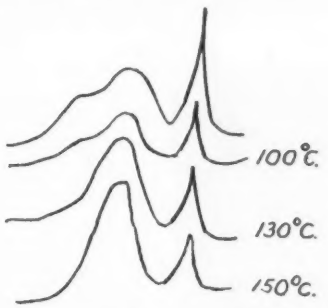


FIG. 2—Microphotometric curves for the (002) reflections. Sharp peaks indicate the platinum line

TABLE I—*Values of the Lattice Constants* a *and* c

Tempering Temp., °C.	Tempering Time	*a*, Å.	*c*, Å.	*c*/*a*
Room	10 years	2·846	2·880, 3·02	1·012, 1·062
100	1 hr.	2·846	2·882, 3·00	1·013, 1·054
125	,,	2·848	2·886	1·013
150	,,	2·852	2·886	1·012
175	,,	2·857	2·884	1·009
200	,,	2·859	2·878	1·006
225	,,	2·861	2·872	1·004
250	,,	2·863	2·870	1·003
275	,,	2·861	2·870	1·003
300	,,	2·863	2·867	1·002
325	,,	2·863	2·865	...
350	,,	2·861	2·863	...
650	,,	2·861	2·861	...

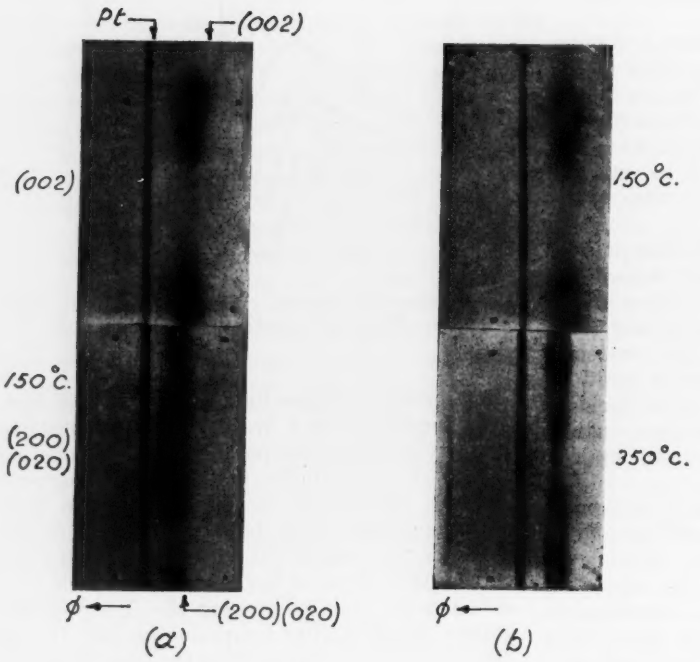


FIG. 3—(*a*) Reflections (002) and (200), (020) after tempering at 150°C. (*b*) Reflections (002) after tempering at 150° C. and 350° C.

Note.—In Fig. 3*a* the positions of (002)—and (200), (020)—spots are compared ((002) *above*, (200), (020) *below*). In Fig. 3*b* the positions of (002)—spots are compared after tempering at 150° C. (*above*) and at 350° C. (*below*).

photographed one after another on separate films and the spots (002) and (200), (020) do not overlap.

In Table I are given the results obtained in measuring the lattice constants a and c. For the initial state and tempering at 100° C., two pairs of values of c are given in accordance with the splitting of the spots. It is seen from the table that the constant c of the tetragonal lattice appearing after tempering at 100–150° C. is still considerably greater (2·880 Å.) than the constant of the α-iron lattice (2·861 Å.). As the tempering temperature rises this constant gradually decreases and approaches that of α iron, and for tempering at 300–350° C. the difference lies within the limits of experimental errors. The constant a remains smaller than that of α iron at a tempering temperature below 200° C.

Thus the tetragonal structure of tempered martensite does not disappear at least before the temperatures 250–275° C. are reached. The distance between the maxima of (002) and (200), (020) spots varied from 2 mm. for a tempering temperature of 125° C. to 0·4–0·5 mm. for 250–275° C.

Figure 2 gives the microphotometric curves of the reflections of (002). The sharp maxima belong to the (220) line of platinum. The split spots observed in the initial condition of the specimen and after tempering at 100° C. do not divide completely, the darkening between the maxima being highly intensive. Thus it follows that a considerable part of the martensite possesses intermediate values of the constant c lying between 3·02 Å. and 2·88 Å. This confirms the results[1, 2, 11] obtained on polycrystals, which show that a highly inhomogeneous tetragonal structure occurs at definite stages during tempering. After tempering for 1 hr. at 130° C. the variation range of c greatly diminishes. However, considerable inhomogeneity of the structure can still be observed also after tempering at 150° C., which is confirmed by the great diffuseness of the spots and the higher value of c (2·886 Å.), as compared with that determined for the second spot at the initial stages of decomposition (2·880 Å.). It is seen from Table I and Fig. 2 that as the intensity of the first maximum decreases, the second maximum is somewhat displaced towards the first one. It follows that for a considerable part of the martensite after tempering at 125–150° C. the constant c does not take the values it attains during the initial stages of decomposition.

Certain conclusions concerning the inhomogeneity of the tetragonal structure and its effect on the diffuseness of the lines can be drawn by comparing the width of the interference lines of (002) and (200), (020) planes. The width was measured at half the height of the maximum of the photometric curve; the results of the measurements will be found in Table II. In the case of split spots (initial condition and tempering at 100° C.) the total width of double spot (002) was

TABLE II—*Comparison of Widths of Interference Lines of* (200), (020) *and* (002) *Planes*

Tempering Temp., °C.	Tempering Time	Width for $R = 28{\cdot}6$ mm., mm.	
		(200), (020)	(002)
Room	10 years	0·9	2·6
100	1 hr.	0·9	2·3
150	,,	1·1	1·3
200	,,	1·0	1·0
250	,,	0·9	0·9
300	,,	0·8	0·8
350	,,	0·7	0·7

measured at half the height of the greater maximum. In tempering below 200° C. the width of the (002) spots remained greater than that of the (200), (020) spots. After tempering at 200° C. and above, the width of (002) spots becomes equal to the width of (200), (020) spots within the range of experimental errors. In the case of very great inhomogeneity the diffuseness of the (002) interference lines must be higher than that of (200), (020), owing to a more rapid change of the constant c with the carbon content. If the widths of both interferences become equal, it means that the width is determined mainly by factors other than the inhomogeneity of the tetragonal structure. From Table II it follows that after tempering at 200° C. and above, the inhomogeneity of the concentration of the solid solution becomes comparatively insignificant. In any case, it plays but a small part on account of the broadening of the line of steel tempered in this temperature range, and the diffuseness depends mainly on other factors (lattice distortion, particle size).

III—Discussion of the Results

The use of single crystals in the study of martensite decomposition processes in tempering brings to light a number of important features of the decomposition process and of the structure of tempered martensite.

The appearance of the split spots of (002) in tempering at room temperature and at 100° C., points to a so-called " two-phase " character of the transformation of the solid solution at definite stages of its decomposition. At the same time the distribution of the intensity (Fig. 2) shows that the tetragonal lattice passes through all the intermediate states which correspond to a gradual decrease of the carbon content in the solution. An essential feature detected in this investigation is that the constants of the tetragonal lattice of martensite do not reach the value of the α-iron constant after the " first transformation " (100–150° C.), *i.e.*, tempering at 100–150° C. does not bring about complete decomposition of the solid solution.

(1) On the basis of the changes in the martensite interferences in tempering, the decomposition process of a supersaturated α solid solution can be represented as follows. In the lattice regions where decomposition has already started, the rate of carbon precipitation is sufficiently high as compared with the time required for the transformation of the whole volume. But in these regions the carbon content rapidly reaches a certain limit after which further precipitation is exceedingly slow, and the decrease of carbon concentration in this region of the lattice practically ceases. The increase in tempering duration raises the total volume of the solid solution areas in which decomposition takes place. After being kept at room temperature for ten years, more than half the volume was found to take part in the decomposition process, the axial ratio of the tetragonal lattice in a considerable part of this volume having decreased from 1·06 to 1·012–1·013. At 100° C. the same relation between the decomposed and the undecomposed volumes is achieved after about 1 hr.[10] After tempering for 2 hr. at 100° C. less than 10% of the whole volume preserves the initial carbon concentration in the solution.[10] Upon tempering for 1 hr. at 125° C. no regions of the solid solution with initial carbon concentrations remained, but a considerable part of the volume still had intermediate values of the axial ratio. Tempering at 150° C. greatly decreases the inhomogeneity of the concentration, and the axial ratio $c : a$ approaches 1·012–1·013, *i.e.*, the " limiting " value which can also be reached at room temperature.

Thus the change of structure at the first transformation consists of the decrease of the axial ratio of the tetragonal lattice down to a certain " limiting " value sufficiently stable in this temperature range and the formation of a carbon-rich phase. The product of the first transformation is therefore a partly decomposed solid solution which is sufficiently stable in keeping some carbon in this range of temperature. The precipitated phase, as shown by the investigation[7] carried out on single crystals, is a carbide different from Fe_3C and which is in a state of high dispersity, the carbide particles being obviously distributed inside the crystals of the solid solution.

The next stage of martensite decomposition, different from the first in character, is a further considerably slower gradual approach of the solid-solution lattice to that of the α iron. At normal tempering durations this process extends over a temperature range of 150° to 300–325° C. The " limiting " concentration achieved at a given tempering temperature decreases as the temperature itself rises. This concentration changes very

little with increase in tempering time at a given temperature.

(2) The question of what quantity of carbon remains in the solution after the first transformation and how does it change with further increase in tempering temperature will now be considered. The possibility of determining the tetragonal lattice constants a and c seems to make the solution of this problem a very easy affair. It is, however, complicated by the fact that in the concentration region under discussion the relation between the lattice constants and carbon content in the solution was not determined, such a relation being available only for concentrations above 0·6%.[2, 11] Of course, in the case of a tetragonal lattice and concentrations below 0·6% the relation between the constants and carbon concentration obtained by extrapolation could be assumed with sufficient certainty that extrapolation to the zero carbon concentration will readily give the α-iron constants. But it is possible that the lattice of the solid solution is not tetragonal in the whole concentration range. Investigations[12] have shown that within the solubility range at 700° C. the stable α solid solution has the cubic lattice of α iron whose constant grows with increase of carbon concentration. There is no reason to believe that a solution with the same concentration, but obtained either during diffusionless transformation at quenching or during gradual

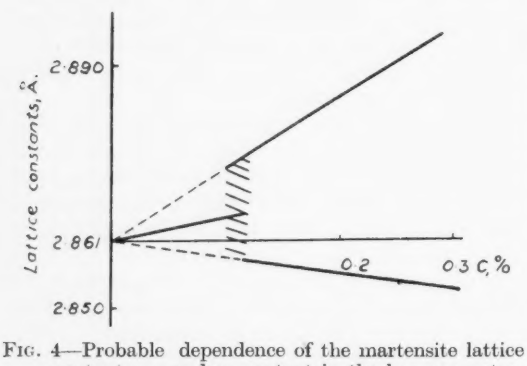


FIG. 4—Probable dependence of the martensite lattice constants on carbon content in the low concentration range

precipitation of carbon from a supersaturated solution, would have a different lattice. Thus, during precipitation of carbon it should be expected that in a certain concentration zone lying not very far from pure iron, the tetragonal lattice becomes a cubic lattice with the α-iron constant somewhat increased. The rate of the variation of the cubic-lattice constant with change in the concentration can be estimated in the following way. For a 0·1% carbon content the tetragonal-

TABLE III—*Values of Carbon Concentration in Solution Obtained by Various Methods*

Tempering Temp., °C.	Tempering Time	Carbon Content, %		
		As Determined by the Axial Ratio	According to Kaminsky and Katznelson[3]	According to Kurdjumov and Oslon[6]
Room	10 years	0·27, 1·4	...	...
100	1 hr.	0·29, 1·2	...	...
125	,,	0·29	...	...
150	,,	0·27	0·42	0·52
175	,,	0·21	0·37	0·45
200	,,	0·14	...	0·39
225	,,	0·08	0·32	0·32
250	,,	0·06	0·15	0·28

lattice constants must be equal to $a = 2{\cdot}859_5$ and $c = 2{\cdot}873$. The cubic-lattice constant must be equal to $a_k = \sqrt[3]{a^2c} = 2{\cdot}864$Å. for the same concentration. Figure 4 represents the probable relationship between the lattice constants and the concentration.

As the lattice becomes cubic the constant a becomes larger than that of α iron and the constant c decreases abruptly. The possibility of the transformation of the tetragonal lattice into a cubic one is bound to bring about a certain distortion of the experimental values of a and c, and some difficulties arise in the determination of the carbon content. Indeed, if there is inhomogeneity of concentration, regions with a tetragonal lattice as well as regions with a cubic lattice will exist simultaneously. The superposition of the interferences will cause a displacement of the (002) spot in the direction of the smaller values of the constant, and a displacement of the (200) spot in the direction of the larger values.

Thus, if the experimental values of the tetragonal-lattice constants are made use of in the determination of the carbon concentration in the solution, lower values than actual ones should be expected.

In the third column of Table III the values of the carbon concentration in a solution are given as obtained by using the experimental values of the ratio $c : a$ (Table I). The carbon-content values were determined from extrapolation of the straight line representing the relation between the ratio $c : a$ and carbon concentration.

Also given in Table III are the values of the carbon content in a solution as obtained by Kurdjumov and Oslon by measuring the width of the lines, and the values obtained by Kaminsky and Katznelson for steels with 0·89 and 0·74% of carbon by measuring the specific volume after

tempering. As mentioned before, the first of these methods is likely to give somewhat exaggerated values. Thus the actual quantities of the carbon remaining in the solution must lie between the values due to the two X-ray methods. The method of determination by the change in the specific volume[8] is based on data concerning the changes in the structure of steel in tempering, obtained by X-ray methods[6, 7, 13] and by measuring the thermal effects.[9, 13]

To obtain more accurate data concerning the carbon content in the solution it is necessary to establish the relation between the lattice constants of martensite and the carbon content for concentrations below 0·3% of carbon. Higher accuracy in the measurement of the constants in the temperature range 250–400° C. is essential if reliable determination of the carbon remaining in the solution in this range of temperatures is desirable. The available data are sufficiently reliable to maintain that for medium- and high-carbon steels tempered at 150° C. the carbon content remaining in the solution lies between 0·3% and 0·5%; after tempering at 300° C., less than 0·1% of carbon remains in the solution. Precise measurements of the constant of the α phase of high-tempered steel show that after tempering at 500° C. the solution contains less than 0·01% of carbon.[15]

It should be noted that martensite with a cubic lattice, which is supposed to exist in the range of about 0·1% carbon concentration, has nothing in common with the "cubic" martensite or β martensite. According to Honda the latter is considered as a solid solution having the same concentration as the tetragonal martensite but with a different distribution of the carbon atoms. The measurement of the constants a and c as done in this paper clearly shows that there is no cubic martensite in tempered steel in the sense of Honda.*

(3) As mentioned above, the isothermic decomposition of the supersaturated solid solution of carbon in α iron consists of two different stages. The first is characterized by a rapid decrease in the concentration of the solid solution down to certain values depending on the tempering temperature, and the second by a further very slow precipitation of carbon. This process should be interpreted in the same way as similar phenomena observed in ageing of supersaturated solid solutions in non-ferrous metals which have been explained by Konobeevski.[14]

The explanation follows from a relation between the concentration of the solution and the size of the dispersed precipitated particles as determined by the Thomson-Freundlich formula

$$\ln \frac{S}{S_\infty} = \frac{2\mu\tau}{RT\rho r} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

in which r is the radius of the particle, S_∞ the concentration of saturation with respect to the large crystal, S the concentration of saturation with respect to the particle of radius r, and μ, ρ, and τ the molecular weight, density, and surface tension.

As the nuclei of the carbide phase grow, the carbon concentration in the region of the solid solution surrounding the growing particle is lowered. Rapid growth of the particle proceeds as long as the solid solution around is supersaturated with carbon and until this supersaturation is sustained at the expense of carbon diffusion taking place as a result of the concentration gradient. As the carbon immediately around the particle is being used up, the rate of the "delivery" of carbon atoms rapidly decreases and the rate of growth slows down. Such a rapid decrease in the rate of growth is apt to take place when the carbide crystals are still so small that corresponding concentration S will differ from S_∞.

The "two-phase" character of the first stage of decomposition, which stands out clearly in the authors' tests in tempering at room temperature and at 100° C., and the practical constancy of the "limiting" increase (compared with S_∞) concentration during the whole of the first stage of decomposition enable an idea to be formed about the kinetics of the process, as follows: Around each carbide nucleus, at the expense of its growth, a certain solid-solution region with a "limiting" carbon concentration is formed. Farther away from the carbide particle the concentration gradually increases up to the initial magnitude. After the carbide particle has grown to a certain size its growth practically ceases as explained above, and the solid-solution region with lowered concentration (compared with initial concentration) also ceases "to grow." If a constant growth of the transformed solid-solution regions took place in the process of the "two-phase" stage, a complete decomposition of the solid solution through a considerable volume according to formula (1) would be expected. Thus each carbide nucleus is used only for the transformation of a certain limited volume of the solution from an initial to a "final" state (for instance, from the lattice with $c : a = 1{\cdot}06$ to a lattice with $c : a = 1{\cdot}012$) The time in which every transformed region reaches its "limiting" volume is small compared with that required for the whole of the two-phase stage of the process.

* *See also* references 2, 3, 5, and 6.

The volume of the transformed part of the solid solution increases mainly owing to the increase in the number of these regions, but not as a result of their growth. The kinetics of the "two-phase" process in the case under consideration are determined thus only by the rate of formation of carbide nuclei. If the number of nuclei n appearing in a unit volume per unit time is assumed

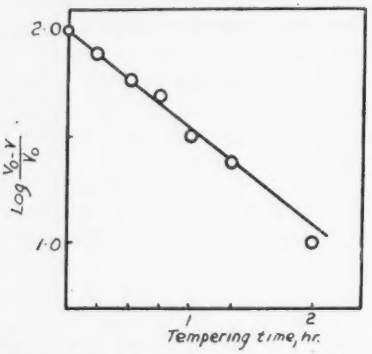


FIG. 5—Plot of the logarithm of the undecomposed martensite volume against tempering time at 100° C.

constant, the increase in the transformed volume per time dt is given by :

$$dV = v\,(V_o - V)ndt \quad \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

in which V_o is the initial volume, V the volume of the transformed part at the time t, and v the volume of the transformed solid-solution region surrounding each carbide particle. We obtain the formula :

$$\frac{V_o - V}{V_o} = e^{-nvt} \quad \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

which represents the relationship between the untransformed volume and the time t. This relationship does not contain the initial period of the slow increase in the transformed volume characteristic of crystallization processes (such as the eutectoid decomposition of austenite) in which the continuous growth of new phase regions plays a certain part. In the case under consideration the decomposition rate is a maximum just at the initial moments of tempering and gradually decreases with time. Such a kinetics of the process is characteristic of martensite decomposition.[6, 10, 13]

Figure 5 represents the relation between the logarithm of the undecomposed part of martensite $(V_o - V)/V_o$ and the time of tempering at 100° C. The values of $(V_o - V)/V_o$ are taken from the diagram obtained by Kurdjumov and Sachs[10] for the " two-phase " stage of decomposition. In agreement with equation (3), the experimental values follow closely the straight-line law.

The second stage, proceeding considerably slower and bringing about a further decrease in the concentration of the solid solution, must be determined, in accordance with equation (1), by the growth of the carbide particles (coagulation process) as a result of the diffusion of carbon atoms over large distances. The growth of the carbide particles brings about a decrease in the concentration of the solid solution. The rate of this process becomes noticeable at higher temperatures when the diffusion is great enough to transport the carbon atoms over great distances. The " limiting " concentration of the solution decreases.

REFERENCES

1. G. KURDJUMOV : *Zeitschrift für Physik*, 1929, vol. 55, p. 187.
2. G. KURDJUMOV and E. KAMINSKY : *Zeitschrift für Physik*, 1929, vol. 53, p. 696.
3. A. IVENSEN and G. KURDJUMOV : *Journal of Physical Chemistry*, 1930, vol. 1, p. 41.
4. G. KURDJUMOV : *Archiv für das Eisenhüttenwesen*, 1932–33, vol. 6, p. 117.
5. G. HÄGG : *Journal of the Iron and Steel Institute*, 1934, No. II, p. 439.
6. G. KURDJUMOV and N. OSLON : *Journal of Technical Physics*, 1939, vol. 9, p. 1891.
7. M. ARBUSOV and G. KURDJUMOV : *Journal of Technical Physics*, 1940, vol. 10, p. 1093 ; *Journal of Physics U.S.S.R.*, 1941, vol. 5, p. 101.
8. E. KAMINSKY and D. KATZNELSON : *Journal of Technical Physics*, 1945, vol. 15, p. 182.
9. P. GRUSIN, G. KURDJUMOV, and R. ENTIN : *Metallurg*, 1940, No. 8, p. 15.
10. G. KURDJUMOV and G. SACHS : *Zeitschrift für Physik*, 1930, vol. 64, p. 325.
11. F. ÖHMAN, *Journal of the Iron and Steel Institute*, 1931, No. I, p. 445.
12. V. GRIDNEV and others : Physical Technical Institute and Metallurgical Institute, Dniepropetrovsk, 1941. (Not published.)
13. G. KURDJUMOV : " On the Theory of Steel Quenching and Tempering." Reports of All Union Society of Scientists, Engineers, and Metallurgists (VNJTOM). Symposium in Memory of Dmitry Tchernov, 1940, pp. 96–125.
14. S. KONOBEEVSKI : *Transactions of the Academy of Sciences of the U.S.S.R., Chem. Ser.*, 1937, No. 5, p. 1209 ; *Zeitschrift für physikalische Chemie*, 1934, A, vol. 171, p. 25 ; *Journal of the Institute of Metals*, 1943, vol. 69, p. 397.
15. G. KURDJUMOV and E. ENTIN : " Temper-Brittleness of Steels," *Metallurgisdat*, 1945.

Some Experiments on Quenching Media*

By F. W. Jones, Ph.D.,† and W. I. Pumphrey, M.Sc.‡

SYNOPSIS

In a search for a standard test for the comparison of the hardening properties of different quenching media, cooling rates were determined at the centre of a silver cylinder. An attempt was made to correlate the cooling rates thus obtained with the hardnesses found in quenched 1½-in. dia. cylinders of a high-carbon–chromium–molybdenum steel.

No simple method of correlation was apparent. Further quenching experiments were carried out with stainless-steel cylinders of various diameters, and qualitative agreement was obtained between predictions based on the cooling rates of the stainless-steel cylinders and hardnesses found experimentally in quenched cylinders of hardenable steels. The experiments with the silver cylinder showed that the value of the heat-transfer factor " h *" as determined experimentally varied considerably with temperature. For purposes of hardness correlation the effective value of "* h *" was found to depend also on specimen size.*

I—INTRODUCTION

FOR the comparison of the hardening powers of different quenching media some simple standard test, on the lines, for example, of the Jominy test for the comparison of the hardenabilities of different steels, would be very useful. Although there is much to be said for the direct method of hardness measurement on actual quenched specimens, it is uncertain to what extent the results of an experiment on one particular size of specimen made from one particular steel are applicable to other steels and other sizes of specimen, hence, some general test would be of value.

During the past 40 years there have been many publications on the subject of the cooling rates given by different quenching media. Much of the work, however, has been uncorrelated and is not susceptible to generalization. Just before the war a start had been made on the problem of testing quenching media, by the Alloy Steels Research Committee. Russell[1] determined the cooling curves of a silver ball, and Stanfield[2] the cooling curves of a cylindrical steel specimen; again, however, it is somewhat uncertain to what extent their results are of general application. A useful contribution to a general solution of the problem was later made by Rose,[3] who used the silver-ball test to determine the heat-transfer factor of a number of quenching media as a function of temperature. When the work described in the present paper was nearly completed a copy was obtained of a recent publication by Krainer and Swoboda[4] on somewhat similar lines in that an attempt had been made to correlate the results of silver-ball tests with the hardnesses obtained in quenched steel cylinders. The methods of treating the problem used by Krainer and Swoboda differed in several respects from those of the present investigators, however, so that it was felt that the publication of the present results would be of interest.

On commencing work on the problem a test of the silver-ball type appeared to offer most promise for assessing the cooling properties of different quenching media. Experiments have therefore been carried out with a silver specimen. At the same time, since the ultimate criterion of quenching efficiency is the hardening developed in steel, parallel experiments were done with steel specimens in order to determine to what extent the results of the tests with the silver specimen could be applied to the hardening of steel. During the course of the investigation it became clear that the correlation of the two sets of results was no simple matter, and as an intermediate step, time–temperature curves during quenching have been taken at the centres of austenitic stainless-steel cylinders of various diameters. Hardness predictions based on the cooling rates in the stainless-steel cylinders were found to be in qualitative agreement with hardnesses found experimentally in quenched bars of hardenable steel.

Five quenching oils were used in the experiments, but most of the work has been done with three quenching media: Cold water, hot water,

*Received 17th September, 1946. The work described in this paper was carried out at the National Physical Laboratory, Teddington.

†Brown-Firth Research Laboratories, Sheffield.

‡Metallurgy Department, Birmingham University.

and one of the quenching oils (oil No. 2). Details of the quenching oils used are as follows :

Oil No. 1 ... Gulf-Super quench oil (new).
Oil No. 2 ... Cotton-seed oil (old).
Oil No. 3 ... Silvertown oil *M2* (new).
Oil No. 4 ... Duckham's oil *Q44S2* (new).
Oil No. 5 ... Silvertown oil *Q2* (new).

Interest in the hot water arose from some previous experience with the quenching of specimens of simple shape made from hypereutectoid steels. In this application, somewhat contrary to expectations, warm water has given results comparable, as regards hardening, with cold water, with considerably less tendency to cracking, so that experiments with this particular medium were of practical interest.

While the results obtained in the investigation are somewhat limited it is felt that the deductions made from them form a useful contribution toward a better understanding of the cooling processes involved during quenching. It should be said that in the present investigations comparisons between the different quenching media have been made purely on the basis of cooling rate and hardness produced in quenched steels. The other very desirable attribute of a quenching medium, that it should not cause quench-cracking, has been entirely neglected.

II—Experiments with the Silver Specimen

(1) *Specimen and Quenching Apparatus*

The following attributes are desirable in a specimen for a standard quenching test :

(*a*) Uniformity and reproducibility of thermal conductivity.

(*b*) Absence of thermal effects due to phase changes.

(*c*) Non-scaling surface and reasonably high melting point.

(*d*) Relatively simple and symmetrical geometrical shape for ease of mathematical treatment of results.

(*e*) Ease of machining.

The silver ball used by Russell[1] and others[3] satisfies the first four requirements, but is not simple to machine, and in practice the cooling is not symmetrical, the under surface cooling faster than the upper surface. A silver cylinder was therefore considered preferable to a sphere.

The apparatus employed for rapid quenching of the specimen was similar in principle to that used by Russell in his investigations. A rather larger quantity of the quenching medium (2 gal.) was, however, used for each test and provision was made for agitation, since in practice some agitation during quenching is usually provided. An oil-tight joint between the stainless-steel thermocouple tube and the specimen was ensured by a suitable welding technique. The apparatus used for the quenchings is shown diagrammatically in Fig. 1. In carrying out a quenching test, the quenching specimen was heated to the required temperature in the vertical furnace and soaked for a short time. The holding screw was then released, allowing the specimen to fall vertically into the quenching-jet orifice, the specimen being guided down centrally by means of the thermocouple-protecting sheath running in the guide rolls. By a careful adjustment of the trip, the trip-switch in the thermocouple circuit was caused to operate at the instant the specimen

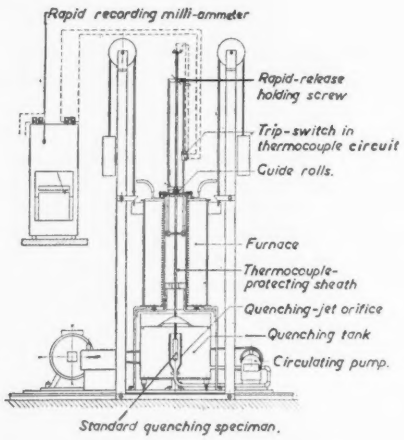


Fig. 1—The quenching apparatus

reached the surface of the oil in the jet orifice ; this momentary short-circuiting of the couple circuit caused a slight kink in the curve given by the rapid-recording milli-ammeter and so recorded accurately the instant of quench of the specimen. Both the recorder and the circulating pump were started some moments before the release of the specimen, and kept running until the recorder indicated that the specimen had attained the temperature of the quenching medium. A record of the zero position of the recorder needle was taken at the beginning and end of every quench.

The quenching medium was contained in the tank and circulated through the orifice by means of the pump, exactly 2 gal. of coolant being used in each test. In the case of the oil-quenchings

each oil was heated to 40° C., before testing, by means of a gas heater placed beneath the tank. In practice, during quenching, it is usual to agitate the specimen. A rate of flow of the quenching medium past the surface of the specimen of 1 ft./sec. appeared to be an average degree of agitation for hand-quenching. From the dimensions of the present apparatus it was calculated that this rate of flow would be obtained

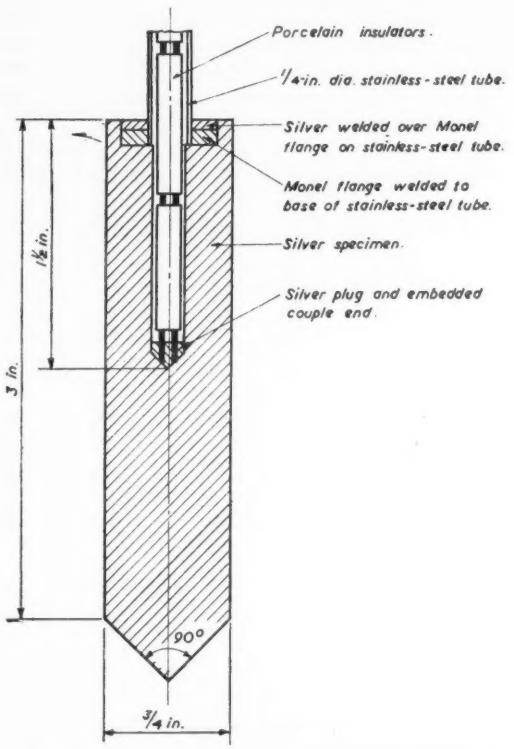


FIG. 2—Complete silver specimen for cooling-rate measurements

with a circulation of the quenching medium of 5 gal./min. This rate of flow was employed in all the quenching tests reported unless a statement is made to the contrary and the flow was checked at frequent intervals during the investigation. The apparatus was so adjusted that the quenching specimen rested exactly in the centre of the orifice during the quench. In the few cases where no agitation of the quenching medium was used, the quenching-jet orifice was removed to prevent undue restriction of the volume of liquid employed in the quench.

Experiments were carried out using a silver quenching specimen, cylindrical in shape. The construction of the silver specimen, the method for ensuring an oil-tight seal between specimen and couple sheath, and the method of attaching the couple wires to the specimen can be seen by reference to Figs. 2 and 3. The specimen was $\frac{3}{4}$ in. in dia. × 3 in. long and was machined at one end to a 90° cone with the object of giving streamlined flow during quenching. A length-to-diameter ratio of 4 : 1 was chosen. According to French and Klopsch[5] this ratio ensures freedom from end effects, so that the cooling at the centre approximates to that in an infinitely long cylinder. The couple wires were fixed at the base of the central couple hole in the silver specimen by the

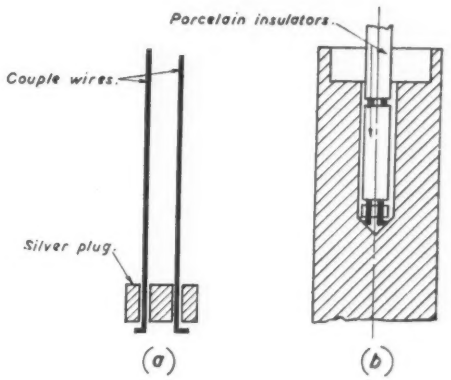


FIG. 3—Couple wires and silver plug (*a*) before insertion and (*b*) inserted into the silver specimen

method illustrated diagrammatically in Fig. 3. The silver plug attached to the ends of the couple wires was hammered well down into the metal at the base of the couple hole, and on the first heating to the quenching temperature, plug and silver specimen sintered together, ensuring an intimate contact of couple and specimen. A " split couple " of this type, in which the specimen is part of the junction, ensures no thermal lag between specimen temperature and the e.m.f. registered by the couple. The preliminary experiments were carried out using a Chromel–Alumel couple, but owing to the rapidity with which the silver attacked this couple at high temperatures, a silver–platinum couple was substituted for the base-metal couple and was used in all the subsequent quenchings with the silver specimen. This couple was calibrated before and after the completion of the investigation and was found not to have altered in calibration by more than 3·5° C. at the highest temperatures involved. The method of obtaining a permanently oil- and water-tight joint between

the stainless-steel couple tube and the silver specimen is illustrated in Fig. 2. A Monel flange was welded to the base of the couple tube and this flange was in turn welded to the silver. No decay in the quality of this joint was noticeable even after some thirty violent quenches.

(2) *The Amplifier and Recorder*

A Tinsley D.C. amplifier [6] and rapid-recording milli-ammeter were employed to follow the rapidly varying thermocouple e.m.f.'s. during the quenchings. The recording milli-ammeter employed was of the variable-speed type, drum speeds of 3, 6, and 12 in./min. being obtainable with it. These speeds were accurate to within $\pm$ 1%. It was suspected that the speed of response of the recorder was rather slow for accurate recording of the more rapid time–temperature curves, particularly those obtained with the silver specimen quenched into cold water.

To check this the following experiment was carried out. A thermocouple e.m.f. of 34 mV. was applied to the instrument and then instantaneously reduced to zero by short-circuiting the thermocouple. (With the particular amplifier used the response was independent of the resistance of the thermocouple circuit.) From the record obtained in this way the damping and inertial factors of the recorder were calculated and the magnitude of the corrections to the experimental time–temperature curves determined. Appreciable distortion of the curve occurred with the silver specimen quenched into cold water. The corrected values of the times to reach different temperatures for water and for oil No. 2 over the steepest part of the curve are given in Table I. In view of the fact that the second decimal place of the times given in Table I has no great significance it will be appreciated that the correction in the case of the oils is of the same order as the experimental error. Since it has not been found possible to make quantitative use of the experimentally determined curves with the silver specimen, they are given in their uncorrected forms in all succeeding sections.

(3) *Results*

The quenching properties of five typical quenching oils and of hot and cold water were examined. The temperature of the hot water was 80° C. Although this temperature is considerably higher than that used in practice it was felt that using this temperature would emphasize the effect of increasing water temperature.

An experiment with non-agitated water at 80° C. showed that the silver specimen cooled more slowly in this medium than in any of the oils. Since earlier experiments* had indicated that with steel bars the quenching properties of non-agitated hot water were superior to oil, it was thought that this apparent anomaly was worth investigating.

The results obtained with the silver specimen are given in Table I and the time–temperature curves (the time at which the specimen reached a temperature of 800°C. has been taken as zero) are shown plotted in Fig. 4. In all cases three curves were taken using a quenching temperature of 815° C. The reproducibility with the oils was quite good, the variation in the time to cool through any 100° C. temperature interval usually being of the order of $\pm$ 10% ; rather larger variations were obtained with water. The results given represent the average of the three curves taken with each medium.

TABLE I—*Times to Cool through 100° C. Intervals for the Silver Specimen Quenched in Different Media*

Quenching Medium†	Time, sec., to cool from 800° C. to :						
	700° C.	600° C.	500° C.	400° C.	300° C.	200° C.	100° C.
Agitated cold water at 20° C.	$0{\cdot}3_8$	$0{\cdot}6_3$	$0{\cdot}8_6$	$0{\cdot}9_6$	$1{\cdot}0_9$	$1{\cdot}2_4$	$2{\cdot}0_9$
Agitated oil No. 1	$1{\cdot}1_5$	$1{\cdot}7_0$	$1{\cdot}9_8$	$2{\cdot}3_3$	$3{\cdot}8_1$	$7{\cdot}0_6$	$13{\cdot}8_6$
,, ,, No. 2	$0{\cdot}8_9$	$1{\cdot}2_2$	$1{\cdot}6_4$	$2{\cdot}5_6$	$4{\cdot}4_8$	$7{\cdot}6_7$	$15{\cdot}3_2$
,, ,, No. 3	$1{\cdot}1_5$	$2{\cdot}0_5$	$2{\cdot}4_7$	$3{\cdot}0_7$	$4{\cdot}4_2$	$7{\cdot}0_2$	$13{\cdot}7_2$
,, ,, No. 4	$1{\cdot}0_8$	$1{\cdot}9_1$	$2{\cdot}4_1$	$3{\cdot}1_1$	$5{\cdot}0_1$	$8{\cdot}0_4$	$15{\cdot}4_9$
,, ,, No. 5	$1{\cdot}1_8$	$2{\cdot}2_8$	$3{\cdot}0_6$	$3{\cdot}6_6$	$5{\cdot}2_6$	$8{\cdot}2_1$	$15{\cdot}0_6$
Agitated water at 80° C.	$2{\cdot}9_0$	$5{\cdot}2_0$	$6{\cdot}8_5$	$8{\cdot}1_0$	$9{\cdot}1_0$	$10{\cdot}0_3$	$12{\cdot}7_8$
Non-agitated water at 80° C....	$4{\cdot}9_7$	$10{\cdot}0_2$	$15{\cdot}1_2$	$18{\cdot}6_7$	$20{\cdot}4_7$	$21{\cdot}6_5$	$26{\cdot}5_5$
Agitated cold water at 20° C. (corrected) ...	$0{\cdot}2_7$	$0{\cdot}5_4$	$0{\cdot}7_9$	$0{\cdot}8_5$	$0{\cdot}9_1$	...	...
Agitated oil No. 2 (corrected)	$0{\cdot}8_0$	$1{\cdot}1_8$	$1{\cdot}7_4$	$2{\cdot}5_9$	$4{\cdot}3_3$	...	...

† A key to the quenching oils used is given in the Introduction to the paper

* These early experiments are not described in the present paper, but *see* Table II.

The results with cold water required relatively large corrections and so may be subject to some error.

The implications of the results will be discussed in a subsequent section.

III—The Cylindrical Steel Specimens

Cylindrical specimens $1\frac{1}{2}$ in. in dia. were machined from steel having the following composition :

C, %.	Si, %.	Mn, %.	Ni, %.	Cr, %.	Mo, %.
0·74	0·25	0·34	0·21	1·43	0·23

This steel will henceforth be termed steel No. 1.

It was desired to find out whether the hardness obtained in the bars, using the different quenching media, could be correlated with the results of the quenching tests described in Section II. For this purpose it was of importance to quench all the cylinders from the same temperature, since the hardenability of this steel varies with temperature. To obtain maximum differentiation between the quenching media the quenching temperature was fixed such that specimens quenched from it into a variety of different media (giving both fast and slow rates of cooling) gave centre hardnesses lying on the steeply sloping portion of the Jominy curve of this steel. Preliminary experiments revealed that the optimum temperature from this point of view was 815° C. (*see* Fig. 5) and in consequence all quenchings with the silver and with the $1\frac{1}{2}$-in. dia. steel cylinders were done from this temperature.

Some difficulty was anticipated in the correlation of the hardnesses on the $1\frac{1}{2}$-in. dia. cylinders with the quenching tests of section II. To facilitate the comparison, therefore, the time–temperature curve at the centre of each of the $1\frac{1}{2}$-in. dia. cylinders was recorded during the quenching. This, together with the Jominy bar curve, permitted hardness to be related to cooling rate for the steel.

The design of the cylindrical bars was as illustrated in Fig. 6. The asbestos end-pieces were attached to prevent appreciable cooling from the ends of the steel cylinder during quenching. The steel cylinders were quenched into five different media, oils 1, 2, and 4, agitated cold water, and non-agitated water at 80° C. The soaking time at the quenching temperature was 20 min. The cylinders were all hardened from the initially annealed condition, a different specimen being used for each quench ; after quenching, each cylinder was sectioned transversely just below the bottom of the central couple hole and hardness measurements were made across a diameter of the slit section. Each specimen was stirred round by hand in the respective quenching media (except that quenched into water at 80° C.) at a standard rate corresponding to a rate of flow of coolant of about 1 ft./sec. past the specimen. A record of the cooling rate established at the centre of the cylinder was taken on the recording milliammeter. One Chromel–Alumel thermocouple was used for all the quenchings on the steel

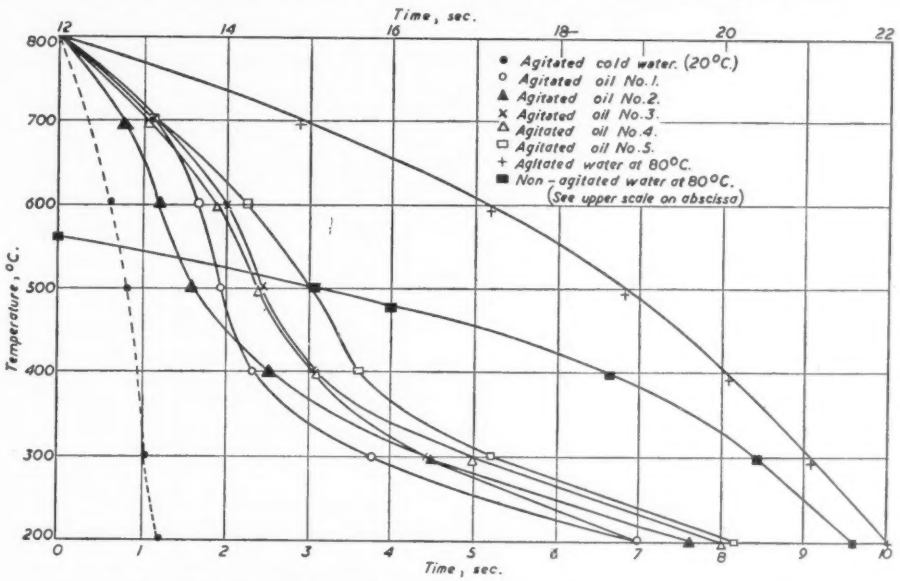


Fig. 4—Time–temperature curves for the silver specimen, quenched in various media

cylinders. The response of this couple was checked against couples welded to the bases of the central couple holes of two cylinders which were quenched into cold water and into oil No. 4. The results showed that the method of forcing the couple into the specimen, illustrated in Fig. 6, did not introduce any appreciable error due to temperature lag between the specimen and the couple. The Chromel–Alumel couple used for the quenchings was calibrated before and after the investigation and was found not to have altered in calibration by more than 1·5° C. at the highest temperature involved.

Before any deductions can be drawn regarding the hardening ability of different quenching media resulting from their different cooling powers, it is

TABLE II—*Hardness Values and Cooling Time over Transformation Range Obtained by Quenching in Various Media*

Quenching Medium	Time, sec., for centre to cool from 500° to 250° C.	Hardness at centre of quenched cylinder, D.P.H.
Agitated oil No. 1	85	472
,, ,, No. 2	83	487
,, ,, No. 4	84	381
,, ,, No. 4*	81	383
Non-agitated water at 80° C....	24·4	703
Agitated cold water (20° C.) ...	15·4	710
,, ,, ,, (20° C.)* ...	17·2	703

* Welded couple

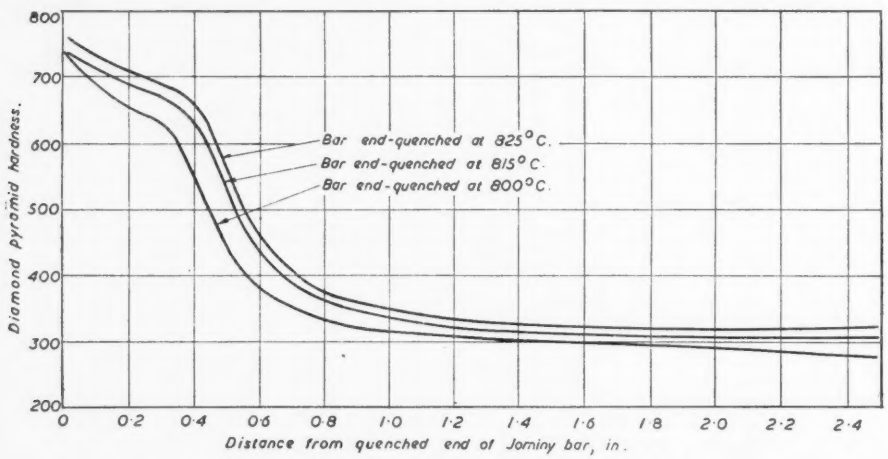


FIG. 5—Hardenability curves of steel No. 1 at different quenching temperatures

necessary to know the dependence of the hardness developed in a steel upon cooling rate. Since with all quenching media the cooling rate varies with temperature and furthermore varies with temperature in a different way with different media, the temperature interval over which the cooling rate should be considered in order to correlate the cooling rate with hardness is a matter of some importance.

The half-temperature time[7] has frequently been used as a basis for correlation, but it might be expected that the most suitable temperature range over which to measure the cooling rate would be that range in which the steel actually transforms on quenching. For the steel at present under consideration it has been shown[8] that the transformation range on continuous rapid cooling lies between 550° C. and 250° C., depending to some extent on the cooling rate. Inspection of the hardness–temperature curves given in Fig. 27 of the same paper[8] shows that for hardnesses above 370 D.P.H. the transformation does not commence until the temperature has dropped below 500° C. The centre hardnesses obtained with 1½-in. dia. cylinders are from 380 D.P.H., upwards, and so for the purposes of the present paper the temperature interval 500–250° C. has been taken as the transformation range. The cooling time over this temperature range and the hardness results obtained with the quenched steel cylinders are given in Table II.

These results indicate that the difference in hardness given by oils 1 and 2 on the one hand and oil No. 4 on the other, are not explained by considerations of the cooling times between 500° and 250° C. Differential curves (cooling time over 50° C. against temperature, *see* Fig. 7) indicate that the transformation occurs at about

475° C. in the case of oil No. 4 and at a lower temperature with oil No. 2. Thus, although the time to cool from 500° to 250° C. is the same with both oils, the lower hardness of the bars quenched in oil No. 4 may be attributed to the slower cooling rate at the higher temperatures (about 475° C.). It appears, therefore, that it is impossible to correlate *accurately* the hardness with the cooling time over a particular range of temperature for steels, such as that from which the 1½-in. dia. bars were made, where the transformation temperature varies considerably with cooling rate. However, the cooling time from 500° to 250° C. gives considerably better correlation of hardness with Jominy bar results than that obtained using the half-temperature time proposed by Grossmann,[7] as shown in Table III. With non-agitated water at 80° C. the half-temperature time correlation is very badly out.

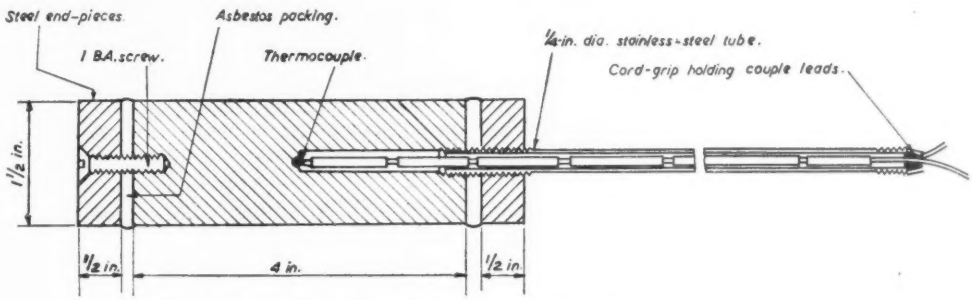


FIG. 6—Form of steel cylinder for quenching in the different media

IV—ATTEMPTS AT CORRELATION OF RESULTS ON SILVER CYLINDER AND 1½-IN. DIA. STEEL BARS

The time–temperature curves for the silver cylinder quenched in various media are shown in Fig. 4, and the cooling-rate/temperature curves in Fig. 8. Cold water gives fastest cooling, whilst the cooling rates given by hot water are particularly slow at high temperatures. No obvious conclusions can be drawn as to the relative merits of the different oils. The fact that several of the time–temperature curves of the oils intersect means that any attempt to put them in an order of merit as regards their cooling properties will depend on the temperature chosen for comparison of cooling rates. The intersection of the curves indicates that the heat-transfer factors vary with temperature in a different manner with the different media. From Russell's tables[10] the cooling curves and hence the cooling rates of a silver cylinder quenched in a medium can be calculated if it is assumed that the heat-transfer factor of the medium and the thermal conductivity and diffusivity of the silver do not vary with temperature. In the calculation the following values have been taken :

Thermal conductivity, k	$= 0{\cdot}97$ cal./g./sec./°C.
Specific heat, S	$= 0{\cdot}059$ cal./g.
Density, ρ	$= 10{\cdot}3$ g./c.c.
Diffusivity, a^2	$= k/S\rho = 1{\cdot}6$ sq. cm./sec.
Radius of silver cylinder, b	$= 0{\cdot}96$ cm.

The above are approximate mean values for the important temperature range since the constants vary somewhat with temperature. Values of the thermal conductivity are not given in the literature[11] for temperatures above 500° C., but on the basis of results for other pure metals[12, 13] it may be estimated that the thermal conductivity of silver would decrease by about 10%, certainly less than 15%, from 0° to 800° C. From 0° to 800° C. the specific heat increases by 18%[14]; the density decreases by 5% and the radius of the cylinder increases by about 2%, giving a decrease in the

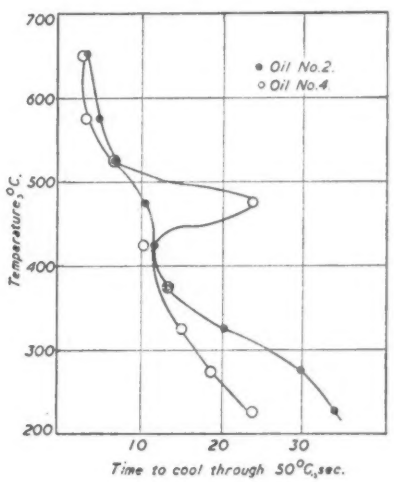


FIG. 7—Differential cooling curves for 1½-in. dia. cylinder of steel No. 1, quenched in oils 2 and 4

TABLE III—*Comparison of Correlation by Cooling Time from 500° to 250° C. with Correlation by Half-Temperature Time*

Quenching Medium	Correlation by Cooling Time from 500° to 250° C.				Correlation by Half-Temperature Time				Observed Hardness, D.P.H.
	Time to Cool from 500° to 250° C., sec.	Equivalent Jominy Distance, in.	Calculated Hardness, D.P.H.	Difference between Observed and Calculated Hardnesses, D.P.H.	Half-Temperature Time, 815–417° C., sec.	Equivalent Jominy Distance, in.	Calculated Hardness, D.P.H.	Difference between Observed and Calculated Hardnesses, D.P.H.	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Agitated oil No. 1 ...	85	0·59	450	22	53·4	0·67	397	75	472
„ „ No. 2 ...	83	0·58	457	30	58	0·70	383	104	487
„ „ No. 4 ...	83	0·58	457	75	70	0·80	360	22	382
Agitated cold water ...	16·2	0·17	695	12	16·6	0·32	657	50	707
Non-agitated water at 80° C.	24·4	0·23	678	25	59·4	0·71	380	323	703

The equivalent Jominy distances in column (3) were obtained by plotting the time to cool from 500° to 250° C. against distance along the Jominy bar, using the time-temperature curves given by Russell and Williamson,[9] which were also used to determine the Jominy distances in column (7) equivalent to the half-temperature times in column (6)

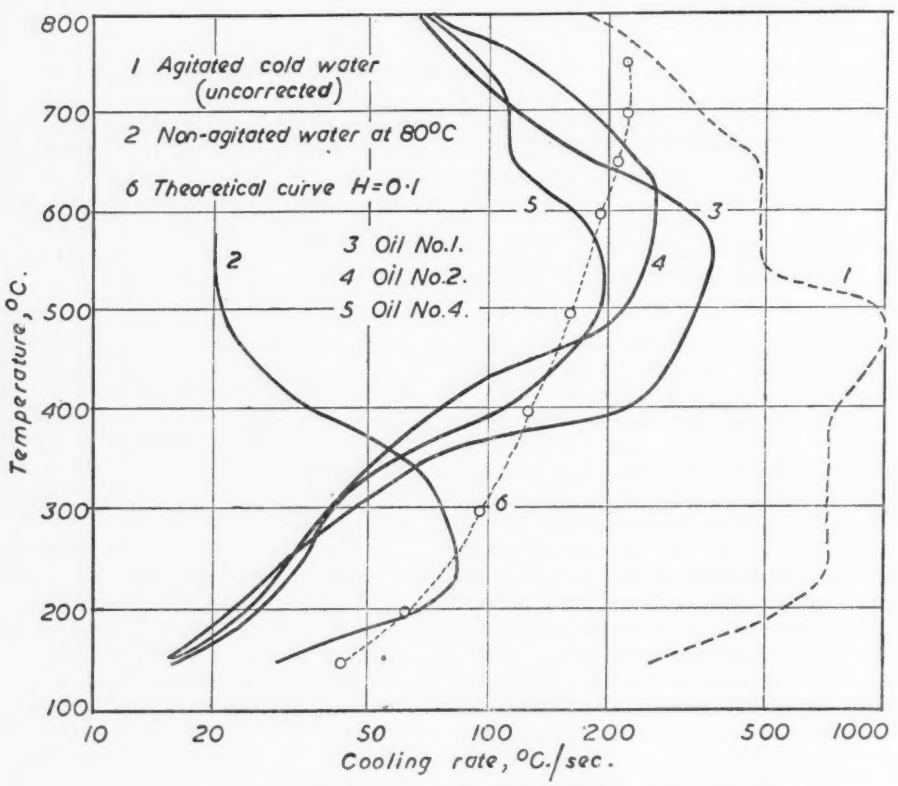


FIG. 8—Cooling rates in a silver specimen quenched in various media

diffusivity of about 20%. No great error is introduced therefore by taking mean values for these constants.

In Fig. 8 the cooling rate is shown plotted against temperature for a silver cylinder quenched in a theoretical medium for which $H = 0 \cdot 1$, assuming the mean values of the thermal constants given above. The differences between the theoretical curve and the experimental curves are far greater than can be accounted for by any variations in the thermal constants of silver, *e.g.*, the cooling rate is the same on curves 2 and 6 of Fig. 8 at a temperature of 260° C.; it differs by a factor of nearly 10 at a temperature of 600° C. The cooling rate for oil No. 1 is 370° C./sec. at 550° C., the theoretical is 180° C./sec.; at 250° C. the cooling rate is 30° C./sec. with oil No. 1 and 80° C./sec. on the theoretical curve. Thus any attempt to explain the differences between the experimental and theoretical cooling curves on the basis of variation in the thermal constants of silver would necessitate the highly improbable assumption that the values of the thermal constants of silver depend on the quenching medium.

It therefore appeared to be of interest to attempt to calculate the rate of heat abstraction by the various quenching media at different temperatures. At any temperature the rate of heat abstraction per unit area per second, dQ/dt, is proportional to the rate of fall of mean temperature of the specimen, *i.e.*:

$$\frac{dQ}{dt} = \frac{\rho VS}{A} \cdot \frac{dT_A}{dt} \quad \text{.....(1)}$$

where V = volume of unit length of cylinder,
A = surface area of unit length of cylinder,

T_A = the mean temperature $= \dfrac{\int T dV}{V}$, where

T = the temperature at any point in the specimen.

In our experiments we have measured the rate of fall of the centre temperature T_c. If the difference between the mean temperature and centre temperature is small we may take the rate of fall of centre temperature as a reasonable approximation to the rate of fall of the mean temperature of the specimen. The temperature difference ΔT between the surface and centre of the silver specimen under steady cooling conditions is given[10] by:

$$\Delta T = \frac{b^2}{4a^2} \cdot \frac{dT}{dt}; \quad \text{.....(2)}$$

substituting the values for silver and taking $b = 0 \cdot 96$ cm., we obtain:

$$\Delta T = 0 \cdot 144 \frac{dT}{dt} \quad \text{.....(2 a)}$$

The fastest cooling rate of the silver specimen observed with any of the oils was about 370° C./sec., obtained with oil No. 1 at 550° C. The rate gives a temperature difference of 56° C. between the surface and the centre of the specimen. In general, the cooling rates are considerably slower than 370° C./sec., and the temperature difference will be usually below 30° C. Alternatively, using Russell's tables[10] and taking $H = hb = 0 \cdot 1$, *i.e.*, $h = 0 \cdot 104$,* which gives faster cooling than any of the oils over the range 700–200° C., the maximum temperature difference between surface and centre is found to be 36° C. It may be shown that, under steady cooling conditions, the mean temperature of a long cylinder is the average of the centre and surface temperatures. Since the surface temperature may be about 30° C. lower than the centre temperature, the mean temperature may be about 15° C. lower than the centre temperature. This difference is not large; for the silver specimen, therefore, the rate of fall of the centre temperature gives a reasonably close approximation to the rate of fall of the mean temperature of the specimen and we may write, in place of equation (1):

$$\frac{dQ}{dt} = \frac{\rho VS}{A} \cdot \frac{dTc}{dt}$$

$$\therefore \frac{dQ}{dt} = \frac{\rho bS}{2} \cdot \frac{dTc}{dt} \quad \text{.....(3)}$$

$$= 0 \cdot 29 \frac{dT}{dt} \quad \text{.....(3 a)}$$

It should be noted that as an approximation ρ, b, and S have been taken as constants in equation (3*a*). The product $\rho\, b\, S$ varies by 13% ($\pm 6 \cdot 5\%$ from a mean) from 0° to 800° C.

Thus the rate of heat abstraction dQ/dt at any particular temperature is given by multiplying the cooling rate (plotted in Fig. 8) by 0·29.

In the theoretical treatment of quenching problems it is more usual to employ the heat-transfer factor, h, rather than the rate of heat abstraction dQ/dt. The relationship between these two quantities may be obtained by assuming that:

$$\frac{dQ}{dt} = C(T_s - T_m) \quad \text{.....(4)}$$

where T_s = surface temperature of specimen,
T_m = temperature of quenching medium, and
C is assumed to be constant.

* Since h is inversely proportional to the thermal conductivity of the specimen this value of h is considerably lower than the corresponding value with a steel specimen.

The heat-transfer factor, h, is then given by :

$$h = \frac{C}{k} \quad \text{.....(5)}$$

$$\therefore \quad h = \frac{dQ}{dt} \cdot \frac{1}{k\,(T_s - T_m)} \quad \text{.....(6)}$$

$$= \frac{\rho b S}{2} \cdot \frac{dT}{dt} \cdot \frac{1}{k\,(T_s - T_m)} \text{ (from equation (3))}$$

$$= \frac{b}{2a^2} \cdot \frac{dT}{dt} \cdot \frac{1}{(T_s - T_m)}$$

$$= \frac{0{\cdot}30}{(T_s - T_m)} \cdot \frac{dT}{dt} \quad \text{.....(7)}$$

taking $a^2 = 1{\cdot}6$ (for silver) to be independent of temperature.

As was pointed out earlier in this section, a^2 varies with temperature and may differ by about $\pm$ 10% from the constant value of 1·6 assumed above, so that the values of h calculated from equation (7) may be in error by the same amount.

From equation (7), h has been calculated as a function of temperature for the silver specimen quenched into still hot water and agitated oil No. 2. The curves are shown in Fig. 9. With hot water the heat-transfer factor varies by a factor of nearly 20, and with oil No. 2 by a factor of nearly 4. These are much greater variations than the errors introduced by assuming that a^2 for silver is independent of temperature.

The usual assumption made in mathematical considerations of quenching, that h is constant, should therefore be regarded with some suspicion. From Fig. 9, for example, it would be impossible to choose a single representative value of h for either quenching medium with any confidence. It should be noted that the values of h given in the curves of Fig. 9 are applicable only to silver, since the value of h depends on the thermal conductivity. In addition, since h varies with temperature, we have found it more convenient to use in succeeding calculations the rate of heat abstraction dQ/dt, the value of which at any temperature can be determined experimentally. For a steel, the value of h at any one temperature may be obtained from the value of h for silver by using the formula :

$$h_{\text{Ag}} \times k_{\text{Ag}} = h_{\text{steel}} \times k_{\text{steel}}.$$

The calculation of the cooling curves at the centres of steel cylinders of various diameters presents considerable difficulties when h varies with temperature. For plates it is still far from simple, but a mathematical solution is possible if different values of h are assumed over different temperature intervals. In view of the difficulties, however, the best form of attack at present available appears to be to use the approximation method due to Schmidt.[15] The calculations by this method are very laborious, but to give some idea of the effects of specimen size, surface and centre cooling curves have been determined for a 1·18-in. (3-cm.) thick steel plate (which is roughly equivalent[4, 16] to a cylinder $1\frac{1}{2}$-in. in dia.) quenched in agitated oil No. 2 and in still hot water. The experimental values of dQ/dt obtained from the cooling-rate curves of Fig. 8 were used for the calculations, details of which are given in Appendix I. Appendix II shows how the method may be applied to cylindrical bars. However, since the calculations for cylinders are even more laborious than for plates, they were in the first place carried out for a 3-cm. plate. The cooling curves are plotted in Fig. 10.

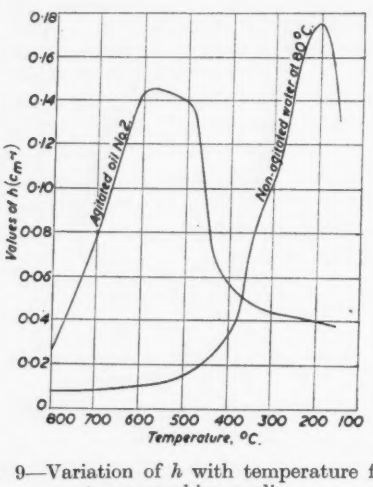


FIG. 9—Variation of h with temperature for two quenching media

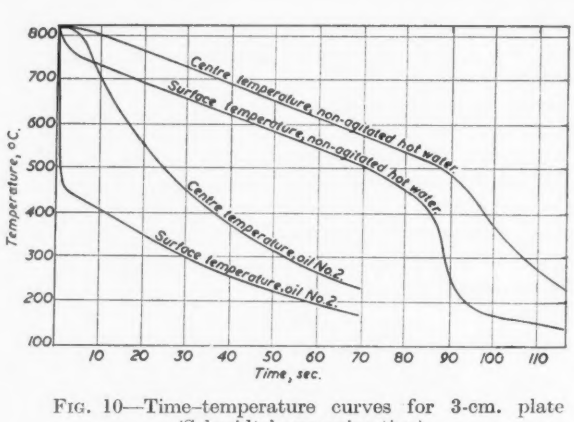


FIG. 10—Time–temperature curves for 3-cm. plate (Schmidts' approximation)

From these curves the times to cool from 500° to 250° C. at the centre are :

Oil No. 2, 39 sec.
Hot water, 26·5 sec.

The calculated interval with hot water is very similar to that obtained experimentally (24·4 sec.) with the $1\frac{1}{2}$-in. dia. cylinder. The figure for oil No. 2 is less than half of the experimental value (83 sec.) ; part of the difference may be due to the energy of the transformation being released in this temperature interval in the case of oil No. 2 ; the transformation energy has, of course, been neglected in the theoretical calculations. The high internal hardness of 703 D.P.H. found in the bar quenched in hot water suggests that in this case the steel has transformed to martensite at a temperature below 250° C., *i.e.*, the energy was liberated outside the range considered. In view of the assumptions made, exact quantitative agreement is not to be expected, but the results are in qualitative agreement with the hardness figures. Krainer and Swoboda[4] also obtained qualitative agreement between actual hardness figures on quenched steel specimens and predictions made from the silver-ball test results using Schmidt's approximation. There are differences between the results obtained by Krainer and Swoboda with the silver ball and those obtained in the present investigation with the silver cylinder. In particular they found that the cooling rate with hot water (60° C.) at 2° 50C. was slightly higher than that with cold water. The cooling rates given by Rose[3] for various oils are of the same order as those obtained by the authors with oils 1 to 4.

Consideration of the cooling curves of Fig. 10 assists in promoting a better understanding of heat-transfer problems during quenching. It is clear that the high heat-transfer factor of oil No. 2 in the temperature range 800–450° C. serves little useful purpose since the surface of the steel plate spends only about 2 sec. in this temperature interval ; the heat-transfer factor below 450° C. is more important. This is in agreement with the conclusion reached by Stanfield.[2] Where the transformation range of the steel is below 500° C., the curves of Fig. 10 indicate that the heat transfer at quite low temperatures (*i.e.*, 300–200° C.) is the determining factor for the centre cooling rates in the range 500–250° C.

V—Reconsideration of the Problem

From the foregoing, it is clear that the problem of the correlation of hardnesses obtained in quenched cylinders with the cooling properties of the quenching medium may be resolved into the following sections :

(*a*) The determination of the rate of heat abstraction dQ/dt of the quenching medium as a function of temperature.

(*b*) Effect of specimen size and conductivity on the centre cooling rates at various temperatures, using the values of dQ/dt obtained in (*a*).

(*c*) The determination of the temperature range for the particular steel considered in which the transformation occurs during continuous cooling.

(*d*) The correlation of the hardness obtained in the steel with the cooling rate through this transformation range.

The values of dQ/dt as a function of temperature may be obtained approximately using the silver specimen ; Schmidt's approximation method can then be used to calculate the centre cooling rates in steel plates of various sizes, in order to determine the effect of specimen size and thermal conductivity. However, this procedure is very laborious and somewhat uncertain in view of the assumptions involved. A more satisfactory procedure would appear to be that of combining sections (*a*) and (*b*) by the direct experimental determination of the centre cooling rates in cylinders of various diameters made from steel free from phase changes below 850° C.

(1) *Determination of Cooling Rates, Using Austenitic Stainless-Steel Cylinders*

Cooling rates at the centres of stainless-steel cylinders, $\frac{3}{4}$, $1\frac{1}{2}$, and $3\frac{1}{2}$-in. in dia., have been determined for three quenching media, oil No. 2, unagitated hot water (80° C.) and agitated cold water.

To enable the results to be of general application, the cylinders were made from 18/8 stainless steel, thus avoiding the complicating effects of the transformation energy. The cylinders were similar in design to the $1\frac{1}{2}$-in. dia. steel cylinders previously considered (*see* Fig. 6), except that in the case of the $\frac{3}{4}$-in. dia. cylinder the two thermocouple wires were welded individually to the bottom of the central couple hole to obviate the possibility of any temperature lag at the relatively fast cooling rates.

Figures 11 to 14 show the centre cooling rate plotted against the temperature for the three sizes of stainless-steel specimen, and also the cooling rate for the silver specimen on a similar scale for ease of comparison. Of the three media considered, cold water gives the fastest cooling rates at all temperatures with the silver specimen, and

this is also true of the three sizes of stainless-steel specimen, although, as might be expected, the difference between the three media becomes very much less as the size of the specimen increases. With the silver specimen, cold water gives a cooling rate about 50 times faster than hot water at 500° C.; with the 3½-in. dia. stainless-steel specimen the cooling rates are in the ratio 1·15 to 1 at the same temperature. Increasing the size of the specimen also tends to smooth out the cooling-rate/temperature curve found with the silver specimen. The change in the point of intersection of the cooling-rate/temperature curves of oil No. 2 and hot water is of interest. Above the temperature of intersection, oil No. 2 is the better quenching medium ; below it, hot water is superior. The temperature at which the curves intersect increases from 360° C. with the silver specimen, to about 610° C. with the 3½-in. dia. stainless-steel specimen. A rather remarkable fact is that hot water gives slightly faster cooling at 450° C. with the ¾-in. dia. stainless-steel specimen than with the ¾-in. dia. silver specimen, in spite of the very much higher thermal conductivity of the latter.

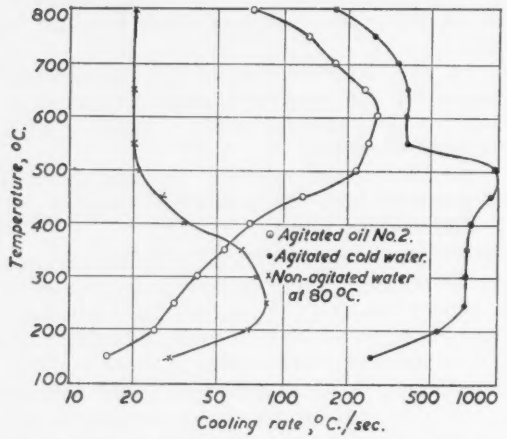


FIG. 11—Cooling-rate/temperature curves for ¾-in. dia. silver specimen

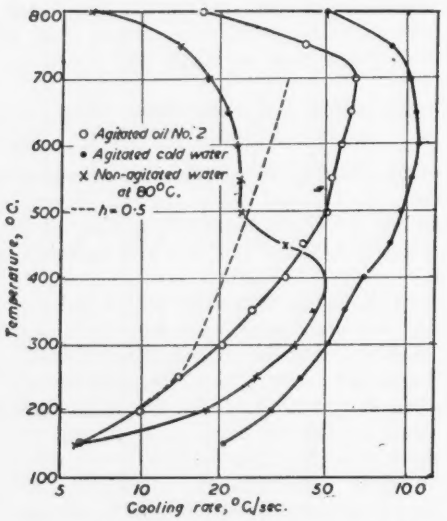


FIG. 12—Cooling-rate/temperature curves for ¾-in. dia. stainless-steel specimen

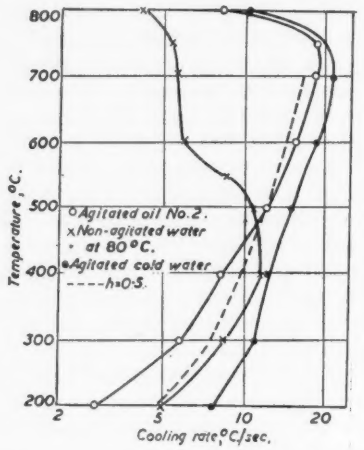


FIG. 13—Cooling-rate/temperature curves for 1½-in. dia. stainless-steel specimen

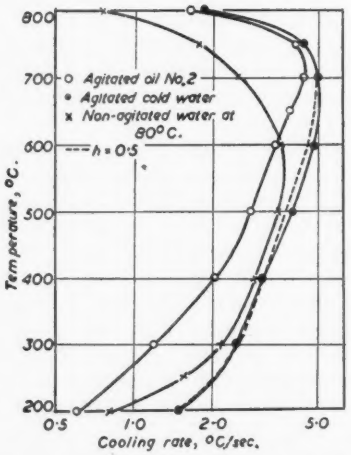


FIG. 14—Cooling-rate/temperature curves for 3½-in. dia. stainless-steel specimen

The temperature difference between the centre and surface is greater with the stainless-steel than with the silver specimen. When the centre temperatures are 450° C., the surface of the stainless-steel specimen has attained a considerably lower temperature than that of the silver specimen and is in a temperature range where the rate of heat abstraction is relatively high (*see* Fig. 11 and equation 3*a*).

From a comparison of the observed cooling rates of the stainless-steel cylinders quenched in oil No. 2 and the rates calculated theoretically, assuming $h = 0{\cdot}5$ cm.$^{-1}$ (*see* Figs. 12 to 14), the deductions shown in Table IV may be drawn, regarding the "effective" value of h, *i.e.*, the value of h required to give agreement between observed and calculated cooling rates for a limited temperature range.

TABLE IV—*Effective Values of* h *for Different Temperature Ranges and Specimen Sizes*

Dia. of Specimen, in.	Effective value of h for Temp. Range :	
	700–600° C.	300–200° C.
$\frac{3}{4}$	Much greater than 0·5	Approx. equal to 0·5
$1\frac{1}{2}$	Slightly greater than 0·5	Less than 0·5
$3\frac{1}{2}$	Less than 0·5 ...	Much less than 0·5

The results in Table IV show that :

(*a*) The effective value of h decreases as the size of specimen increases.

(*b*) The effective value of h increases as the correlation temperature increases.

Fig. 15 is of interest in connection with attempts to correlate the hardness obtained on a Jominy bar with that in quenched steel cylinders. Cooling-rate/temperature curves are shown for $\frac{3}{4}$-, $1\frac{1}{2}$-, and $3\frac{1}{2}$-in. dia. cylinders quenched in oil No. 2 and also in a theoretical medium for which $h = 0{\cdot}5$ cm.$^{-1}$. The cooling-rate/temperature curves at the positions $\frac{1}{4}$, $\frac{1}{2}$, and 1 in. from the quenched end of the Jominy bar obtained from Russell and Williamson's results[9] are also shown for purposes of comparison. It is clear from the curves that difficulties will be encountered in correlating the Jominy results with those on quenched cylinders, particularly if the theoretical cooling curves for the latter are used. For example, at 625° C., a $1\frac{1}{2}$-in. dia. cylinder quenched with a severity of quench of $h = 0{\cdot}5$ cm.$^{-1}$ has the same centre cooling rate as at $\frac{1}{2}$ in. from the quenched end of the Jominy bar; for equal cooling rates at 340° C. the equivalent Jominy distance is $\frac{1}{4}$ in. For the same cooling rates at 675° C. and 275° C. at the centre of a $1\frac{1}{2}$-in. dia. cylinder quenched in oil No. 2, the equivalent Jominy distances are again $\frac{1}{2}$ in. and $\frac{1}{4}$ in.

(2) *Qualitative Correlation between Cooling Rates of Stainless-Steel Cylinders and Hardnesses Obtained with Quenched Steel Bars*

The results with the stainless-steel cylinders give the cooling rates as a function of temperature for cylinders of various diameters quenched into different media. If now we have a steel in which the transformation occurs at a certain temperature during the quench, then the quenching medium which gives the fastest cooling rate through this temperature, in a particular diameter of bar, should give the highest hardness. The application of this principle will be illustrated by two examples :

(a) *Bars of $\frac{3}{4}$ in. and $\frac{1}{2}$ in. in Dia. of Steel No. 2*—From Fig. 12 it would be expected that oil No. 2 would give better hardening than hot water on quenching a $\frac{3}{4}$-in. dia. bar of a steel for which the transformation temperature on cooling was 500° C. or higher. This will certainly also be true for a $\frac{1}{2}$-in. dia. bar, since, as has already been pointed out, the intersection temperature of the cooling-rate curves for hot water and oil No. 2 decreases with bar diameter.

A steel was available for which the transformation temperature on quenching at rates close to the critical cooling rate was about 500° C. This temperature was determined by the method of the interrupted Jominy quench.[8]

The analysis of the steel, which will be called steel No. 2, was as follows :

C, %.	Si, %.	Mn, %.	Ni, %.	Cr, %.	Mo, %.
0·70	0·28	0·84	0·02	0·13	0·02

Cylinders of $\frac{3}{4}$ and $\frac{1}{2}$ in. in dia. were made from this steel and quenched into non-agitated water at 80° C. and agitated oil No. 2. Hardness traverses across the bars are shown in Fig. 16. As was predicted, oil No. 2 has given better hardness figures than hot water in both diameters.

(b) *Cylinders of $1\frac{1}{2}$ in. in Dia. of Steel No. 1*—In contrast to the results described in (*a*) above, it would be expected, from Fig. 13, that with $1\frac{1}{2}$-in. dia. cylinders made from steel No. 1, which transforms on quenching at a temperature below 500° C.[8] the order of superiority of these two quenching media would be reversed and that hot water would give better hardening than oil No. 2. This is in agreement with the results

obtained in Section III. Hardness traverses across the bars quenched in hot water and in oil No. 2 are shown in Fig. 17.

The curves of Figs. 12 and 13 are thus in qualitative agreement with the hardness figures on the $\frac{3}{4}$- and $1\frac{1}{2}$-in. dia. steel bars; where the curves show that one quenching medium gives a faster cooling rate through the transformation range of the particular steel than another, with a certain size of specimen, a higher hardness is in fact obtained.

Should correlation be required involving the cooling rate of a cylinder of intermediate size (say, 2·in. in dia.), it is probable that sufficient accuracy is obtainable in interpolation if the quenched steel bars and predictions made on the basis of the cooling rates of the stainless-steel cylinders, it was thought to be of interest to determine to what extent quantitative agreement could be obtained. In Section III the observed centre hardnesses of the $1\frac{1}{2}$-in. dia. cylinders of steel No. 1 were compared with the figures predicted from the observed cooling times from 500–250° C. If the cooling of a cylinder of steel No. 1 is similar to that of a stainless-steel cylinder quenched in the same medium, then, as outlined at the beginning of Section V, it should be possible to predict the hardness found in the cylinder of steel No. 1 from the cooling time through the transformation range of the stainless-steel cylinder.

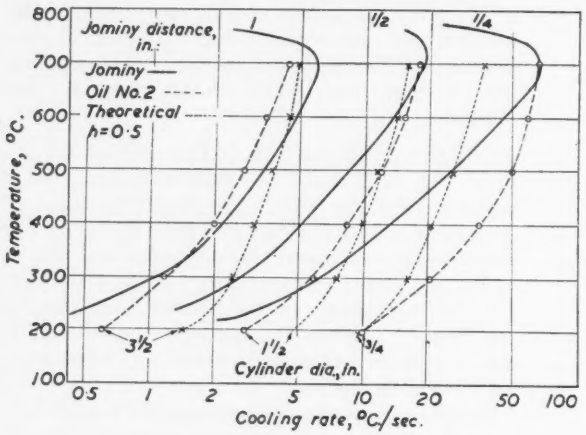


FIG. 15—Cooling curves on Jominy bars and quenched steel cylinders

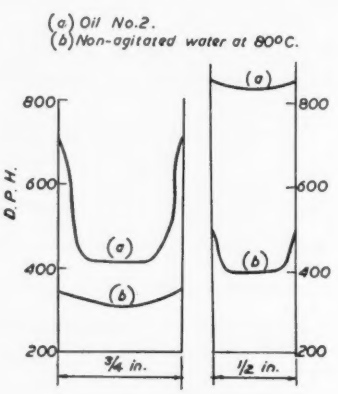


FIG. 16—Hardness traverses across $\frac{3}{4}$- and $\frac{1}{2}$-in. dia. cylinders of steel No. 8

function $(dT/dt)b^2$ is plotted against the radius b. This function varies only slowly with cylinder radius.

The reversal in the apparent quenching efficiencies of hot water and oil No. 2 on quenching the two types of specimen suggests that in comparing two oils, unless the heat-transfer factor of one is higher than that of the other at *all* temperatures, such a reversal may occur. Whether or not a reversal will occur can be determined only by quenching specimens of different sizes, or by use of the Schmidt approximation.

(3) *Attempts at Quantitative Prediction of Hardness in $1\frac{1}{2}$-in. Dia. Steel Cylinders*

Reasonable qualitative agreement having been obtained between the hardnesses developed in The steps in making hardness predictions in this way are given in Table V.

The cooling times for the stainless-steel cylinder were taken from the actual time–temperature curves. The Jominy distances and thus the hardnesses corresponding to these cooling times were obtained as already described in Section III. The agreement between calculated and observed hardnesses is not good; as has already been pointed out in Section III, prediction of hardness on the basis of cooling time may not always be exact. Nevertheless, the disagreement between observed and calculated values for oil No. 2 in Table V is considerably larger than was expected. This discrepancy appears to be associated with a difference between the cooling curves of the stainless-steel cylinders and the cylinders of steel No. 1. Figure 18 shows the

TABLE V—*Prediction of Hardness Values in Steel No. 1 from the Cooling Time through the Transformation Range*

	Oil No. 2	Non-Agitated Water at 80° C.	Cold Water
(1) Cooling time from 500° to 250° C. with stainless-steel cylinder, sec. ...	37·5	25·5	21
(2) Jominy distance to give corresponding cooling times from 500° to 250° C., in.	0·33	0·24	0·21
(3) Hardness at position (2) on Jominy bar, D.P.H.	660	680	690
(4) Observed centre hardness in cylinders of steel No. 1, D.P.H. ...	487	703	710

cooling-rate/temperature curves of the 1½-in. dia. stainless-steel and steel No. 1 cylinders quenched in the three media referred to in Table IV. The reason for the differences between the curves is not clear, but the results may be influenced by the following factors :

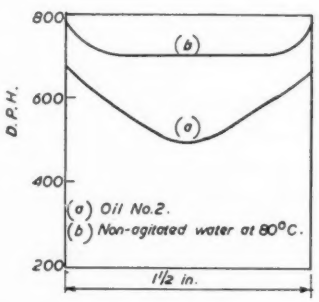


FIG. 17—Hardness traverses across 1½-in. dia. cylinders of steel No. 1

(1) Effect of scale (which may have different effects in the cases of oil and water).

(2) The different thermal conductivities of the two steels ; little is known regarding the thermal conductivity of austenite at subcritical temperatures or of the conductivity of the relatively hard products of austenite decomposition.

(3) The thermal effects of the transformation. As regards the curves of Fig. 18, this effect will not be operative above 500° C. where there is still, however, an appreciable difference between the curves for steel No. 1 and stainless steel quenched in cold water and in oil No. 2.

In view of the discrepancies between the cooling rates of the 1½-in. dia. cylinders of stainless steel and of steel No. 1, it was thought to be of interest to compare the observed cooling rates of the stainless-steel cylinder with the rates obtained using the experimental values of dQ/dt (*see*

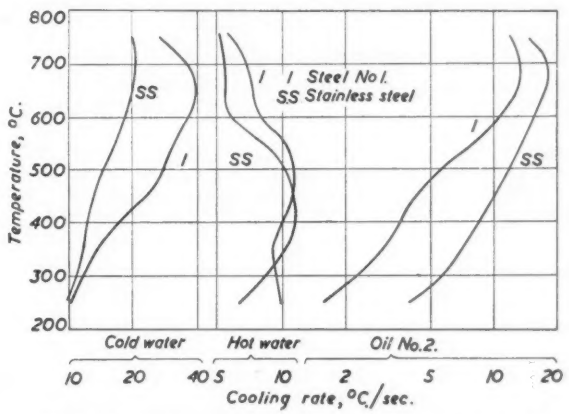


FIG. 18—Cooling-rate/temperature curves of 1½-in. dia. cylinders

Section IV, equation 3*a*) and the Schmidt approximation for cylindrical bars (*see* Appendix II), since factors (1) to (3) enumerated above, which caused difficulties in the attempt to calculate cooling rates with steel No. 1, will not be operative in the case of austenitic stainless steel. The values of the thermal constants for 18/8 austenitic stainless steel were taken from the report[17] on the physical properties of a number of steels from the Physics Division of the National Physical Laboratory. The theoretical and experimental curves for the stainless-steel specimen quenched in non-agitated hot water (80° C.) and for oil No. 2 are shown in Fig. 19. Whilst there are

appreciable discrepancies between the theoretical and experimental curves (it should be pointed out that no adjustable constants were involved in the calculation of the theoretical curves), the general shape of the curves shows fair agreement, indicating that the values of dQ/dt (the rate of heat abstraction) are of the right order.

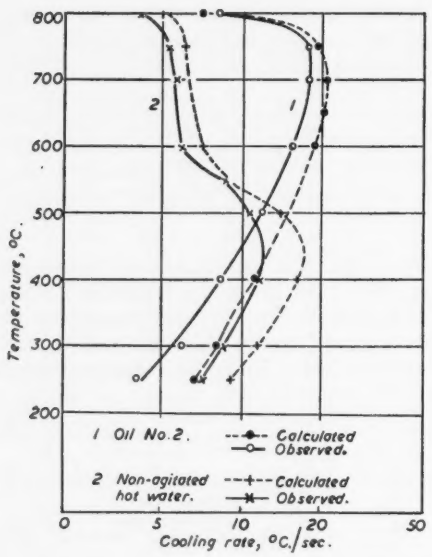


FIG. 19—Observed and calculated cooling-rate/temperature curves for 1½-in. dia. stainless-steel specimens

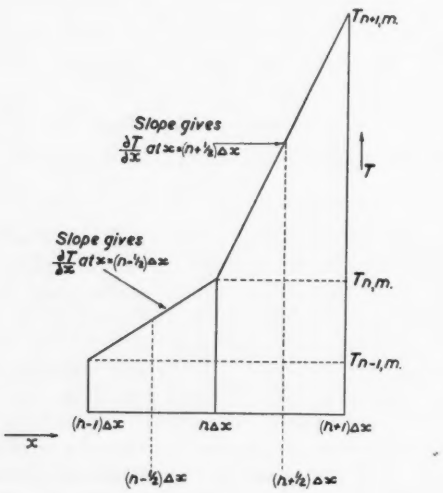


FIG. 20—Temperatures at positions $x = (n-1)\Delta x$, $n\Delta x$, and $(n+1)\Delta x$ at time $t = m\Delta t$ (Schmidt's approximation method)

ACKNOWLEDGMENTS

The work described was carried out in the Metallurgy Division of the National Physical Laboratory on behalf of the Director General of Scientific Research (Defence), Ministry of Supply, by whose permission this paper is published.

APPENDIX I—*Schmidt's Approximation Method*

For linear conduction of heat, we have :

$$\frac{\delta T}{\delta t} = a^2 \frac{\delta^2 T}{\delta x^2} \quad \text{.....(a)}$$

Taking small quantities instead of differentials, we have :

$$\frac{\Delta T}{\Delta t} = a^2 \frac{\Delta\left(\frac{\Delta T}{\Delta x}\right)}{\Delta x} \quad \text{.....(b)}$$

Consider Fig. 20, which gives the temperatures at positions $x = (n-1)\Delta x$, $n\Delta x$, $(n+1)\Delta x$ at time $t = m\Delta t$. $T_{n,m}$ denotes the temperature at a position $x = n\Delta x$ at a time $t = m\Delta t$.

From Fig. 20 :

$$\frac{T_{n,m+1} - T_{n,m}}{\Delta t} = a^2 \frac{\left(\frac{T_{n+1,m} - T_{n,m}}{\Delta x} - \frac{T_{n,m} - T_{n-1,m}}{\Delta x}\right)}{\Delta x}$$

$$T_{m,n+1} - T_{n,m} = \frac{a^2 \Delta t}{(\Delta x)^2}\left(T_{n+1,m} + T_{n-1,m} - 2T_{n,m}\right) \quad \text{.....(c)}$$

If we now choose the time intervals Δt and the distance intervals Δx so that :

$$\frac{a^2 \Delta t}{(\Delta x)^2} = \frac{1}{2} \quad \text{.....(d)}$$

equation (c) becomes :

$$T_{n,m+1} = \frac{1}{2}\left(T_{n+1,m} + T_{n-1,m}\right) \quad \text{.....(e)}$$

This enables us to follow the course of the temperature with time in the *interior* of the body.

For the boundary conditions we have, at the surface :

$$\frac{dQ}{dt} = k\frac{dT}{dx} \quad \text{.....(f)}$$

or, replacing the differentials on the right-hand side by small quantities :

$$\frac{dQ}{dt} = k\frac{(T_{1,m} - T_{o,m})}{\Delta x} \quad \text{.....(g)}$$

where $T_{o,m}$ is the surface temperature and $T_{1,m}$ is the temperature at the interface of the first and second layers at time $t = m\Delta t$.

The temperature drop across the surface layer of thickness Δx is therefore given by:

$$\Delta T_s = T_{1,m} - T^o{}_{,m} = \frac{\Delta x}{k}\left(\frac{dQ}{dt}\right)_{T_s} \quad \ldots\ldots\ldots\ldots (h)$$

To illustrate the use of the method, consider the quenching of a 3-cm. thick steel plate in oil No. 2 and in hot water:

From equation (3 *a*), we have:

$$\frac{dQ}{dt} = 0{\cdot}29\,\frac{dT}{dt},$$

dT/dt being given as a function of temperature in Fig. 8.

If we divide the 3-cm. thick plate into 10 layers, $\Delta x = 0{\cdot}3$ cm., and take as typical of steels of the type of No. 1 the values:

$$k = 0{\cdot}07 \text{ cal./cm./sec./°C.}$$
$$a^2 = 0{\cdot}06 \text{ sq. cm./sec.,}$$

we have from equation (*h*):

$$\Delta T_s = \frac{0{\cdot}3}{0{\cdot}07} \times 0{\cdot}29\left(\frac{dT}{dt}\right)$$
$$= 1{\cdot}25\left(\frac{dT}{dt}\right)$$

and from equation (*d*):

$$\Delta t = \frac{(\Delta x)^2}{2a^2} = \frac{0{\cdot}09}{0{\cdot}12} = 0{\cdot}75 \text{ sec.}$$

ΔT_s is given as a function of temperature in Fig. 21 for oil No. 2 and hot water, using the values of dT/dt given in Fig. 8.

The commencement of the calculation for oil No. 2 is given in Table VI. In the interior of the plate the procedure is shown by the following example:

A temperature of 699° C. at $t = 5\Delta t$ in column

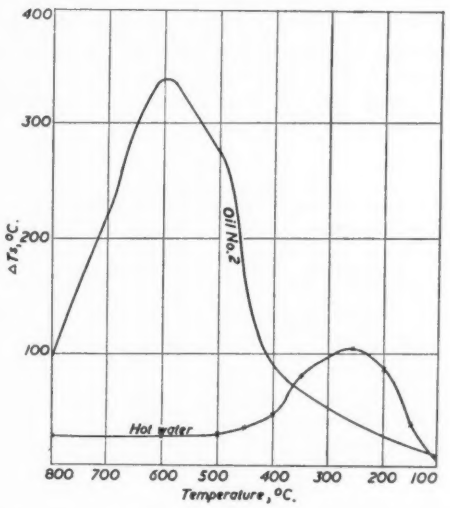


FIG. 21—Curves of ΔT_s as a function of temperature for a 3-cm. plate, using 10 divisions, for oil No. 2.

TABLE VI—*Schmidt's Approximation for Plate 3 cm. Thick, Quenched in Oil No. 2*

Time, sec.	Time in Scale of Δt	Surface	Layer No. in Scale of Δx				Centre	
		(0)	(1)	(2)	(3)	(4)	(5)	(6)
0	0	815	815	815	815	815	815	815
0·75	1	615	815	815	815	815	815	815
1·50	2	460	715	815	815	815	815	815
2·25	3	450	638	765	815	815	815	815
3·00	4	450	608	727	790	815	815	815
3·75	5	440	589	699	771	803	815	803
4·50	6	438	569	680	751	793	803	793
5·25	7	432	559	660	737	777	793	777
6·00	8	426	546	648	718	765	777	765
6·75	9	424	537	632	707	748	765	...
7·50	10	420	528	622	690	736	748	...
37·50	50	266	309	345	375	386	391	386
38·25	51	264	306	342	366	383	386	...
39·00	52	262	303	336	363	376	383	...

(2) is the mean of the temperatures 608° C. and 790° C., in columns (1) and (3) for $t = 4\Delta t$.

At first, some little difficulty arises in fixing the values of ΔT_s, the temperature difference between columns (0) and (1). At $t = 1\Delta t$ we have a figure of 815° C. in column (1). The value of $T_s = 615°$ C. given in column (0) was fixed by trial and error to give a value of ΔT_s of 200° C. which is a rough average value for the temperature range 815–615° C. (*see* Fig. 21). Having obtained a value of 715° C. [$= \frac{1}{2}(615 + 815)$] in column (1) at $\Delta t = 2t$, a value of $T_s = 460°$ C. was obtained to give a value of 255° C. for ΔT_s which is again a rough average value for the range 615–460° C. This procedure may then be continued as long as is necessary.

APPENDIX II—*Schmidt's Approximation for an Infinite Cylinder*

The differential equation of heat flow in an infinite cylinder is :

$$\frac{1}{a^2}\frac{\delta T}{\delta t} = \frac{\delta^2 T}{\delta r^2} + \frac{1}{r}\frac{\delta T}{\delta r};$$

or, taking small quantities instead of the differentials :

$$\frac{1}{a^2}\frac{\Delta T}{\Delta t} = \frac{\Delta\left(\frac{\Delta T}{\Delta r}\right)}{\Delta r} + \frac{1}{r}\frac{\Delta T}{\Delta r}.$$

From Fig. 20, and replacing x by r we obtain :

$$\frac{T_{n,m+1} - T_{n,m}}{a^2\,\Delta t} = \frac{\frac{T_{n+1,m} - T_{n,m}}{\Delta r} - \frac{T_{n,m} - T_{n-1,m}}{\Delta r}}{\Delta r} + \frac{T_{n+1,m} - T_{n-1,m}}{r \cdot 2\Delta r}$$

Taking $r = n\Delta r$:

$$\frac{a^2\Delta t}{(\Delta r)^2} = \frac{1}{2}$$

$$T_{n,m+1} - T_{n,m} = \frac{T_{n+1,m} + T_{n-1,m}}{2} - T_{n,m} + \frac{T_{n+1,m} - T_{n-1,m}}{4n}$$

$$\therefore\quad T_{n,m+1} = T_{n+1,m} + \frac{2n-1}{4n}(T_{n-1,m} - T_{n+1,m})$$

This equation determines the course of the temperature with time in the interior of the cylinder. The temperature at the axis of the cylinder requires special treatment. It may be shown [18, 19] that :

$$T_{o,m+1} = T_{o,m} + 2(T_{1,m} - T_{o,m}) = T_{1,m} - (T_{o,m} - T_{1,m})$$

The temperature gradient across the surface layer is determined in the same way as given in Appendix I for a plate, if n is large (say, $n = 5$ or more), but if n is small ($n = 2$ or 3) it is desirable to use the formula :

$$\Delta T_s = \frac{\Delta r}{k}\cdot\frac{2n-1}{2n}\frac{dQ}{dt}$$

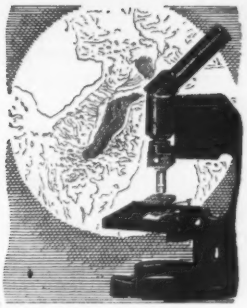
instead of equation (*h*) in Appendix I. This equation takes into account the radial flow in the outermost annulus of the cylinder. As n increases the outermost annulus approximates to a parallel-sided plate, and the equation above approximates to equation (*h*) in Appendix I.

REFERENCES

1. T. F. RUSSELL : *The Iron and Steel Institute*, 1939, *Special Report No.* 24, p. 283.
2. G. STANFIELD : *The Iron and Steel Institute*, 1939, *Special Report No.* 24, p. 299.
3. A. ROSE : *Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung zu Düsseldorf*, 1939, vol. 21, p. 181 ; *Archiv für das Eisenhüttenwesen*, 1940, vol. 13, Feb., p. 345.
4. V. H. KRAINER and K. SWOBODA : *Archiv für das Eisenhüttenwesen*, 1944, vol. 17, p. 163.
5. H. J. FRENCH and O. Z. KLOPSCH : *Transactions of the American Society for Steel Treating*, 1926, vol. 9, p. 33.
6. D. C. GALL : *Journal of the Institution of Electrical Engineers*, 1942, vol. 89, Part II, p. 434.
7. M. ASIMOW, W. F. CRAIG, and M. A. GROSSMANN : *S.A.E. Journal*, 1941, vol. 49, p. 283.
8. W. I. PUMPHREY and F. W. JONES : *The Iron and Steel Institute*, 1946, *Special Report No.* 36, p. 47.
9. T. F. RUSSELL and J. C. WILLIAMSON : *The Iron and Steel Institute*, 1946, *Special Report No.* 36, p. 34.
10. T. F. RUSSELL : *The Iron and Steel Institute*, 1936, *Special Report No.* 14, p. 149.
11. L. C. BAILEY : *Proceedings of the Royal Society*, 1931, A, vol. 134, p. 57.
12. W. G. KANNULUIK : *Proceedings of the Royal Society*, 1933, A, vol. 141, p. 159.
13. F. H. SCHOFIELD : *Proceedings of the Royal Society*, 1925, A, vol. 107, p. 206.
14. F. M. JAEGER and others : *Proceedings, Koninklijke Akademie van Wetenschappen te Amsterdam*, 1932, vol. 35, p. 772.
15. V. H. KRAINER : *Feuerungstechnik*, 1936, vol. 24, p. 4.
16. H. J. FRENCH : *Transactions of the American Society for Steel Treating*, 1930, vol. 17, p. 646.
17. Physics Division, National Physical Laboratory : *Journal of the Iron and Steel Institute*, 1946, No. II.
18. R. JACKSON and others : *Journal of the Iron and Steel Institute*, 1944, No. II, p. 211P.
19. EYERS and others : *Philosophical Transactions of the Royal Society*, 1946, A, vol. 240, p. 1.

B. I. S. R. A.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION



The Distribution of Fuel in Gas Producers*

By M. L. Hughes, M.Sc., F.R.I.C., F.I.M.†

SYNOPSIS

A 'slice' model technique has been employed to examine the distribution of the fuel in gas producers using various charging methods under varying conditions. By means of photographs and graphical diagrams it has been possible to demonstrate the influence on fuel-bed contour and size distribution of :

(a) *The relative diameters of producer body and charging bell*

(b) *The use of a distributing bell in the 'open' position as often utilized in conjunction with mechanical charging systems*

(c) *Variation of ash-bed height*

(d) *The rolling of the charge within the producer*

The improvement possible in producers using hopper-and-bell charging, by installing auxiliary intercepting devices is shown.

The Morgan feed is shown to produce a more satisfactory distribution with much less size segregation. The height of ash bed is shown to have an appreciable effect. The use of the 'flappers' and a disadvantage attached to one of them are discussed.

The results obtained by means of slice models have been checked by using circular models. It is demonstrated that for static types there is a small discrepancy at the centre with the slice model, but for the Morgan producer it was found that the slice model gives a misleading result for the central zone of a complete firebed built up from a succession of feeds. This criticism does not apply to its use for the study of the distribution of individual feeds nor to the results obtained at the perimeter or in 'no rolling' experiments.

Works tests confirm the results given by model experiments for distribution, and conclusions are drawn regarding the probable effect upon gasification.

INTRODUCTION

THE manufacture of producer gas is common to many industries, metallurgical and otherwise, and the fundamental principles of the process are well known. The conditions usually laid down as essential for successful operation of the process are also well known. Briefly, these conditions relate to the chemical and physical properties of the coal used, the steam/air ratio of the blast, and the proper balancing of fuel and blast input so that a fuel bed is maintained of the right depth and temperature. It is then expected that gas of the right composition is produced at the desired rate and at a suitable emergent temperature ; different metallurgical processes call for different results, and the conditions are varied accordingly. For the production of cold clean gas carrying a minimum of tar the operating conditions are

* Paper SM/AD/1/46 of the Steelmaking Division of the British Iron and Steel Research Association. Received 21st October, 1946. This paper is published by authority of the South Wales Steel Sub-Committee. The views expressed in it are the author's, and are not necessarily endorsed by the Sub-Committee as a body.

† The British Iron and Steel Research Association, Swansea Laboratories, Sketty Hall, Swansea.

different from those in gas producers firing open-hearth steel furnaces.

All the above conditions may be specified numerically; those relating to the producer operation may be continuously recorded and in some cases automatically controlled; *e.g.*, emergent gas pressure and also emergent gas temperature by automatically-controlled fuel feed.

There is, however, another condition to be laid down for efficient gasification, which does not lend itself to numerical expression, nor is it easy to determine the extent to which this condition is satisfied in actual practice. This requirement is that *the physical state of the fuel bed should be uniform*. Although gasification is essentially a chemical process, the smooth and uniform progress of the reactions is dependent upon a physical process, *viz.*, the passing of a stream of gases through what is often referred to as a 'bed of broken solids.' This is discussed in greater detail in a later section.

The ideal to be aimed at is, clearly, that the permeability of the bed shall be uniform at all points so that nowhere is there a preferential path for the gaseous stream. It would then follow that the gasification rate would be uniform over the whole horizontal cross-section. This assumes (i) that the fuel condition is uniform, which is implied by the assumption of uniform permeability, and (ii) that coal of one type only is involved so that varying reactivity need not be considered. There would then be no local hot spots, but a uniform and lower temperature. This would lead to less clinkering, which in turn would remove what is probably the most serious menace to uniform permeability, and to good gas production in general, *viz.*, local masses of clinker.

With closely graded coal free from fines and with little caking tendency, it is possible to approach this condition of uniformity to an extent which is satisfactory for normal practical purposes.

(*a*) Such coal has less variation of permeability from point to point because it is relatively uniform in size, the absence of fines being very important.

(*b*) Such coal rolls more and thus distributes itself more evenly over the fuel bed.

(*c*) The absence of caking eliminates another factor influencing permeability, while the fact that a much deeper bed can be used with such non-caking coal serves to damp out small variations of permeability.

The gasification of South Wales gas coals introduces difficulties which are not encountered elsewhere. The present work was, in fact, undertaken with special reference to South Wales conditions. The problems are essentially physical. Excellent gas can be made from these coals, but it is exceedingly difficult to produce and to maintain in the producer the suitable physical conditions which are discussed above. The properties of the coal which cause its gasification to be such a problem are:

(i) An excessively wide size ratio. The commonly accepted ratio of 4 : 1, maximum, is exceeded at least tenfold. The material varies, in fact, from lump to dust. The friable nature of the coal makes the production of fines inevitable, whilst its removal by a grading process would seriously diminish the fuel supply.

(ii) The ash content of the through unwashed coal is generally very much higher than it should be for gasification. In addition, the ash has rather a low fusion point under oxidizing conditions, and this drops badly under reducing conditions.

(iii) The coals are of the caking variety.

These three properties taken together can set up a vicious cycle, the commencement of which is maldistribution with its accompanying segregation. When such a coal is charged unevenly, which is usually the case, certain zones receive little or no coal *directly*. A valley thus forms and coal from adjacent positions rolls into it; as this is the coarser part of the coal, a relatively permeable zone builds up which is still deficient to some extent. Conversely, the adjacent area will have been relatively enriched in its proportion of fines and the total amount will still be greater. The permeability here will clearly be much less, especially since the 'fines' are really so fine that they can pack into the voids of the coarser material. It is not difficult to imagine the difference in the rate of blowing through the two zones—the resistance to the blast rises very rapidly as the voidage is reduced.

It is obvious that instead of blowing the producer at the predetermined (assumed uniform) rate, one zone is seriously overblown and an adjacent zone underblown. The porous zone is consumed much more rapidly, which accentuates the trouble. Sooner or later it is to be expected that surrounding parts of the fire will collapse into the hotter zone, or will be pushed into it by the leveller or agitator.

The significance of the ash-fusion points is now apparent. The overheated zone is likely to clinker, and this tendency is increased if and when a neighbouring partially burned zone is mixed with it, temporarily producing reducing conditions.

Having once begun the clinkering cycle matters become rapidly worse, for clinkers cause channelling which leads to further hot spots, etc. It is unfortunate that the perimeter of the fuel bed is very frequently underfed, for the initial step of porosity due to segregation of coarse material is here reinforced by the wall effect, *i.e.*, the preferential path due to loose packing which arises in all gas producers. Clinker formed here tends

to adhere to the wall, producing the most severe form of channelling and the worst possible conditions for gas making.

The caking property of the coals used contributes to the problem in two ways. The zone from which the coarse material has rolled away is so much less permeable that the fuel is not consumed so rapidly but remains as a visibly colder zone. The upper layers of this zone cake into a solid mass which still further reduces the permeability.

The caking property also means that only a shallow fire can be worked. The presence of a clinker of a given size is clearly more injurious in such a thin fire than it would be in one several feet thick.

If a remedy for this trouble is to be sought, the initial problem of maldistribution must first be attacked, since the coal must be used as it is.

To achieve uniform firebed permeability with fuel of such excessive size ratio is theoretically possible. The coal, varying from lumps of 3–4 in., down to 20–30% below $\frac{1}{8}$ in. can, in theory, be uniformly distributed over the bed, which is the next best thing to a uniformly sized coal. This means, of course, not only that the amount must be equal everywhere, but that the coal sizes must be in the same proportion everywhere.

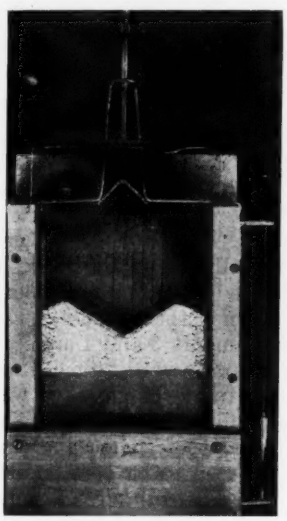


FIG. 1—View of first 'static' slice model: scale, 1 : 24

In practice this is almost impossible since there is segregation, in any case, before the material reaches the producer, as in 'bunker effects,' and especially since only a thin bed can be operated; but it should be possible to improve upon existing results.

It is not suggested that to solve the distribution problem is to solve the whole problem of the gasification of South Wales coals. It would be foolish to make such a claim, for so many factors are involved. It is clear, however, that some of these factors are themselves dependent upon uniform distribution and uniform permeability, as has been partially indicated already. Caking of the fuel is much less harmful if it is uniform over the fuel bed: moderate uniform caking is, in fact, not a serious problem and may even assist.

The clinker problem is of much less serious magnitude if hot spots are eliminated. Nevertheless, it must be admitted that the benefits of good distribution may be nullified by such things as uneven ashing—an example of bad practice which is surprisingly common.

The position is that with good distribution the whole process *begins* 'with its best foot foremost,' whilst with bad distribution, particularly with a porous and deficient perimeter, the process is doomed to bad results from the outset. Just how bad these results may be will be shown later from actual producer studies.

THE 'SLICE MODEL' TECHNIQUE

In order to study this question of distribution a technique has been employed based upon the use of small models as used by Dr. H. L. Saunders * at the Imperial College of Science and Technology, for the study of the corresponding problem arising in the blast-furnace. This work was in fact begun under Dr. Saunders, at the Imperial College.

Figure 1 shows the first model employed. It represents, at a scale of $\frac{1}{2}$ in. to 1 ft., a 'slice' 1 ft. wide across the centre of a static gas producer 8 ft. 6 in. in diameter, having a charging bell of 2 ft. 9 in. diameter. It is fitted with a sliding glass front through which the fuel-bed contour may be observed and photographed. The back is provided with a number of thin, vertical, equidistant slits through which metal shutters 0·01 in. thick can be pushed. The width can be reduced to the equivalent of 7 ft. 6 in. by inserting wooden 'liners' at the sides.

To use this model an 'ash bed' of the desired height is first prepared from fine coal. The charge is then prepared from coal of known sieve sizes mixed in the desired proportion. In most of the experiments the sizes were 10–20 mesh and 40–60 mesh (I.M.M. grading) and the proportion was 50 : 50.

This mixture is charged in small quantities, avoiding segregation, into the space above the 'sliced' bell. This is lowered a fixed amount and is restored by the spring shown. A device is fitted to prevent side swing of the bell. This process is then repeated.

When sufficient material has been charged, the contour is noted and the metal shutters are then pushed in from the back, thus dividing the bed into a number of vertical compartments or 'slots.' The contents of each such compartment are then removed and a sieve analysis made, so that the distribution of each size component can be determined. The ash bed is much finer so that the portion removed with the charge may be sieved out.

* H. L. SAUNDERS AND R. WILD: *Journal of the Iron and Steel Institute*, 1945, No. II, pp. 259–286P.

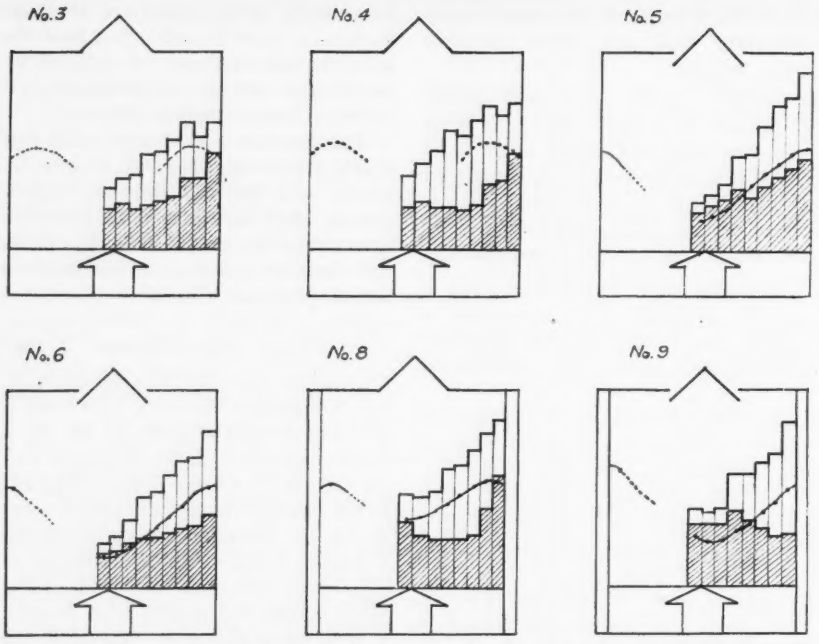


FIG. 2—Contours of fuel beds and distribution of coarse and fine components. Heights of superimposed rectangles are proportional to quantities of coarse (shaded) and fine (unshaded) materials. Nos. 5, 6, and 9 charged with ' open ' bell

Expression of Results

The results are expressed graphically, as in Fig. 2. A simple outline diagram of the model is drawn to scale. The quantity of each component in each slot is represented on this diagram by the height of a rectangle, the coarser material being represented by the lower shaded rectangle and the finer component by the superimposed unshaded rectangle.

The final contour of the charge is, in most cases, drawn on the same diagram and is on the same scale as the outline of the model. It should be noted that the scale used for the heights of the rectangles is quite arbitrary and is chosen in order to show the results as clearly as possible ; it is, however, the same scale in all the diagrams.

Note also, that the actual contour of the charge may differ from the line joining the tops of the upper rectangles. This is due to the varying extent to which the fines occupy the voids amid the larger material. For example, a given *total volume* will always appear of the same *total height* in the diagram. In the model, the material in a compartment containing an excess of the coarse component would occupy a slightly smaller volume due to the virtual disappearance of some of the fines. For this reason, a valley at the walls of the model may not be apparent from the sum of the rectangle heights. This may be seen in Fig. 2, Nos. 3, 4, and 8.

Reproducibility of Results

The early experiments showed that a very satisfactory degree of reproducibility was possible with this model despite the fact that some experimental refinements were not then in use. For example, in Fig. 2, experiments 3 and 4 are seen to agree very well. The charge was 10–20-mesh and 40–60-mesh coal, but the total amount used was not at this stage being maintained constant. The variations in the proportions of coarse and fine in the compartments are seen to be very similar in these experiments. Further examples of reproducibility will be referred to as they arise.

Using the same model, an attempt was made to imitate the conditions existing in Chapman and other producers in which a *fixed* distributing bell is used in the open position. A bell of a given diameter used in this way should produce different distribution results from those of a similar bell used as in hand charging. The model technique served to show this very clearly. The sliced bell was left in the lowered position and the same mixture of 10–20-mesh and 40–60-mesh coal was charged in small portions as before. Experiments Nos. 5 and 6 in Fig. 2 show the results of duplicate experiments. There is a marked change in the ' fuel bed ' contour and in the distribution of the

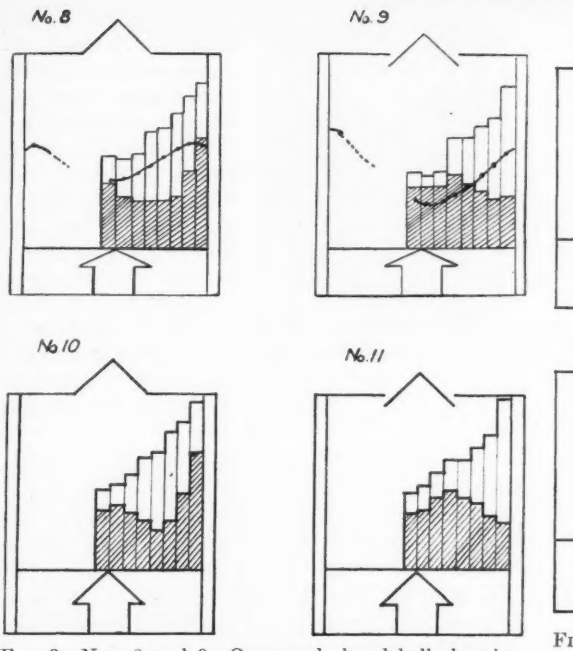


FIG. 3—Nos. 8 and 9 : Open and closed bell charging, using coal for both sizes. Nos. 10 and 11 : As in Nos. 8 and 9, but using marble as the smaller component

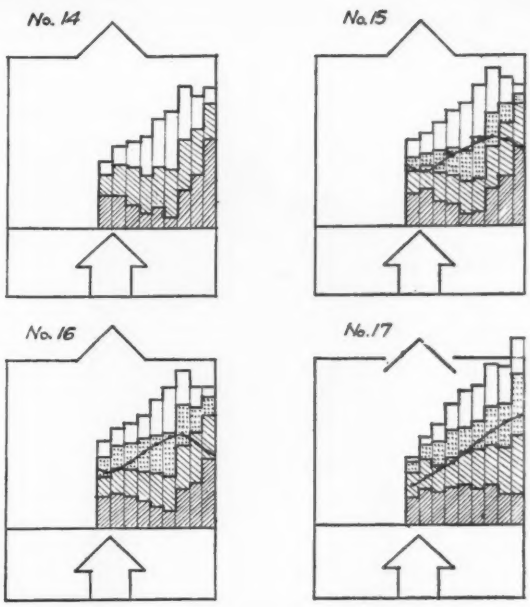


FIG. 4—More complex charges and wider size ratio. Proportion of largest size is shown by bottom rectangle, with component size decreasing in upper rectangles

coarse and fine constituents. These results are obviously due to the fact that the ' fuel ' charged now meets the bell with a certain amount of momentum, and the outward deflection of the charge is appreciably increased. The open bell thus functions as if it were of much greater diameter. In these particular experiments the material was thrown just to the wall and the larger constituent rolled back towards the middle. The resulting increased proportion of fines at the wall is to be regarded as a highly desirable result, for it would damp out the wall effect.

The reproducibility of the results is again seen by comparing Nos. 5 and 6.

The change produced by the ' open bell ' charging is made more pronounced when the width of the model is reduced from the equivalent of 8 ft. 6 in. to 7 ft. 6 in. by inserting side pieces. The coal now actually rebounds from the wall, causing the concentration of fines there to be still more marked, *see* Fig. 2, No. 9. This reduction in width has much less effect on the intermittent charging result, merely reducing the valley at the wall, for the peak of the contour is hardly affected. This is shown in Fig. 2, No. 8. The diagrams indicate the use of side pieces and, in No. 9, that the bell is ' open.'

At this stage it was decided to use marble for the 40–60-mesh component ; the use of marble meant that photographs of the results would indicate the segregation of the coarser particles of coal. Since the density of marble is almost twice that of coal, and also its cleavage is different, it is necessary to show that no serious error is involved in this change. For this reason experiments 8 and 9 just described, were repeated, using 40–60-mesh marble instead of the 40–60-mesh coal.

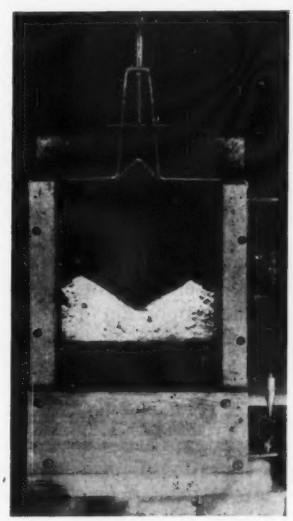


FIG 5—View of contour produced in experiment 14 using a 3-component charge (*see* Fig. 4 for size distribution). Note its resemblance to Fig. 1, in which the size ratio was much smaller

The results, Nos. 10 and 11, may be compared with Nos. 8 and 9, in Fig. 3. The agreement is highly satisfactory and this is confirmed later, using a different type of model.

Experiments Nos. 12 and 13 serve to show that the ' open bell ' effect is just as marked when the ash bed is reduced to half.

In the next series of experiments, Nos. 14–17, Fig. 4, the charge was made rather more complex, and the size ratio greatly increased. The coarse

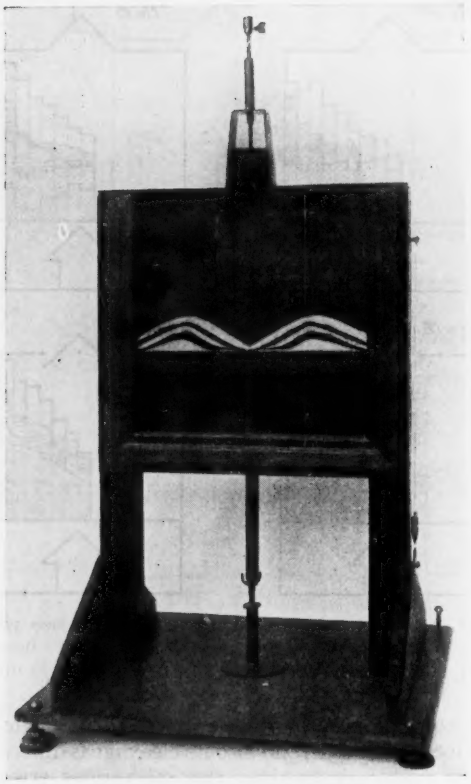


FIG. 6—View of second, larger, slice model of static producer; scale, 1 : 12

was now 0·15–0·10-in. coal, while the fines were 60–80-mesh marble in No. 14 and 80–100-mesh marble in No. 17. In the former there was one intermediate component, 20–40-mesh marble, and in experiments Nos. 15–17 there were two, 10–20-mesh and 40–60-mesh marble. Nos. 15 and 16 are duplicates, and reproducibility is still maintained. The contour is unfortunately missing from No. 14, but Fig. 5 is a photograph of the result. The results show no marked change in contour or in distribution.

A comparison of the results of experiments Nos. 16 and 17 shows that the open-bell effect again gives the **V** contour, and the proportion of the two smaller constituents at the wall is obviously greater. In the diagram the sizes of the constituents diminish upwards.

These experiments representing 'static' producers were later continued with a new model made on twice the scale. Errors of measurement are thus reduced, and larger sizes of material are usable in the charge, which might affect rolling behaviour. This model was designed to use any one of six bells and at two body widths as before, now 9 ft. and 7 ft. 6 in. Instead of an imitation ash bed which had to be re-made each time, a piston was fitted; this could be moved upwards or downwards to represent varying heights of ash-bed surface. This model is shown in Fig. 6.

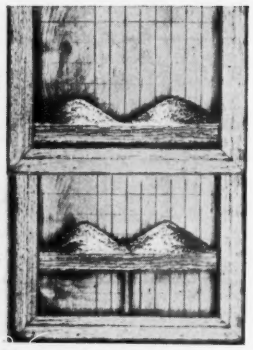


FIG. 7—Change of fuel-bed contour with increased height of 'ash bed'

The effect of such variation of ash-bed height upon the distribution of the charge may be seen from Fig. 7: No. 43 represents a 12-in. ash bed and No. 46 a 36-in. ash bed, in a total working height of 6 ft.

The charge in these tests consisted of 10–20-mesh coal and 40–60-mesh marble in equal amounts. The greater depth and breadth of this model means that enough material for accurate measurement is obtained without building up the bed so much. The photographs show the segregation of the coarser (darker) material towards the walls and centre.

The 9-in. width and $1\frac{3}{4}$-in. bell represent a body/bell ratio of 5·14. These distribution results are shown in the diagrams of Fig. 8. The figures beneath the rectangles represent the percentage of the total charge found in any given compartment. The quantity at the wall is seen to diminish, and that at the centre to increase as the ash-bed level is raised from 12 in. to 36 in.

The Rolling Factor

The excessive proportion of the 10–20-mesh component at the walls is the result of the rolling

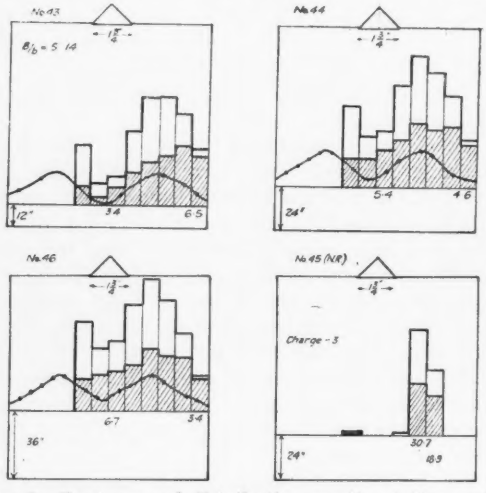


FIG. 8—Contours and distribution results at three ash-bed levels (Nos. 43, 44, and 46). Distribution when rolling is prevented (No. 45)

which occurs. The final distribution is thus made up of:

(*a*) The distribution produced by the charging process, plus

(*b*) The re-distribution caused by rolling.

By separating these two processes it is possible to determine the distribution under (*a*) which provides us with a more direct measure of the charging mechanism from the distribution standpoint.

Diagram 45, Fig. 8, shows the result of such an experiment. The charging conditions were as given above, *i.e.*, a body/bell ratio of 5·14. Instead of placing the piston at a height of 2 in. to represent a 24-in. ash-bed, as in No. 44, it was placed at its lowest position and a set of thin metal shutters was inserted from the back so that they rested on the piston with their upper edges in line 2 in. above. In this way the charged material, on reaching this 2 in. level, dropped into the spaces between the shutters whence it was collected and measured.

These experiments are described as ' no rolling ' and marked N.R., but it is realised that the results are only approximations to the truth. The material may arrive almost completely midway between two compartments and will divide itself between them. If the shutters had been spaced differently the whole of it might have entered one compartment only and the distribution then shown to be more restricted than appeared from the first case. It is clear that the horizontal plane of interception of the charge has a similar effect, causing the distribution produced by a given charging arrangement to appear more restricted at one level than at another.

As indicated on diagram 45, Fig. 8, the experiment was carried out with only a third of the usual charge owing to the limited capacity of the spaces or slots, and the possibility that half of the charge might arrive at one of them, the other half falls in the left, unslotted, part of the model.

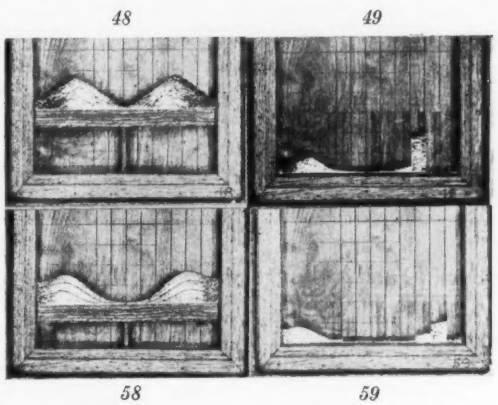


FIG. 9—Nos. 48 and 49: Normal and ' no-rolling ' results, respectively, with body/bell ratio of 4·0; ash level, 36 in.

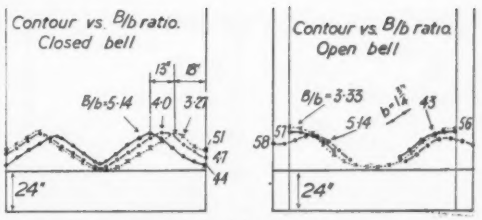


FIG. 10—Variation of fuel-bed contour with varying body/bell ratio using, (*a*) closed bell charging, (*b*) open bell charging

Similar comparisons are shown in Fig. 9. Experiment No. 49 is the ' no rolling ' counterpart of experiment No. 48; the conditions being a $2\frac{1}{4}$-in. bell, a body/bell ratio of 4·0, and an ash level of 36 in. The shadows cast by the shutters may be seen in No. 49.

In the same way No. 59 is the no-rolling result comparable with No. 58. The latter shows the result of using a $1\frac{3}{4}$-in. bell in the ' open ' position, with a 9-in. body. When this is compared with No. 48, in which a $2\frac{1}{4}$-in. bell was used, it is once again seen that the ' open ' bell results in a considerable increase of material at the walls, despite the smaller bell used.

Other experiments on these lines are not individually described but the results are summarized in the curves of Fig. 10.

The static model experiments thus show that:

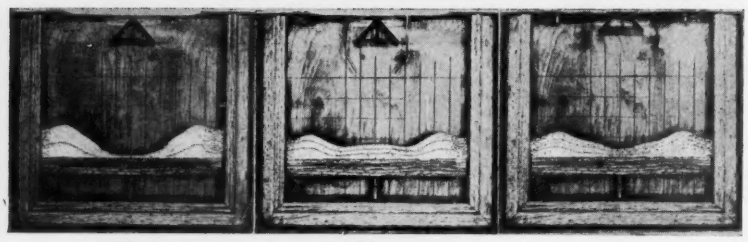
(*a*) With ordinary charging, variation in the body/bell ratio and in ash-bed level merely varies the position of the peaks, corresponding to a circular ridge in an actual producer; *see* Fig. 10 for variation of contour with body/bell ratio. Although the variation shown may not appear to be important, the results of gas-flow experiments intended to demonstrate changes in fuel-bed permeability suggest that the contour variations of Fig. 10, left, are in fact more significant than they seem.

(*b*) With open-bell charging the material is thrown outwards to a far greater extent and the size segregation is different. There is, however, an obvious scarcity of material at the centre. Figure 10 shows also the contours produced by this method of charging with varying body/bell ratio. The lack of material at the centre, together with segregation of the coarser component would also arise under (*a*) if attempts were made to improve the results at the wall by using a much larger bell.

It seems, therefore, that an additional mechanism is needed in order to obtain satisfactory results. This could be a deflecting device arranged in such a way as to divert coal towards the centre of the producer.

The Use of Auxiliary Deflecting Devices

Attempts to deflect coal towards the centre have been made in the past with some measure of success.



60 *61* *67*

FIG. 11—Fuel-bed contour: (*a*) open bell charging, body/bell ratio, 4·0, no deflectors; No. 60. (*b*) Using deflecting blades, No. 61. (*c*) Using deflecting hood, No. 67

The present model technique is very suitable for examining the performance of such devices for improving distribution. In Fig. 11, Nos. 61 and 67 show the contours produced by two such deflecting arrangements and should be compared with No. 60 in which no deflector was used. The improvement in size distribution in No. 61 is seen in Fig. 12.

In No. 61 (Fig. 11) the blades shown in the photograph occupy the central third of the internal width of the model and a *portion* of each charge was deflected inwards. The consistency of the process may be judged from the dotted lines which indicate the contour at three equal stages in the charging process.

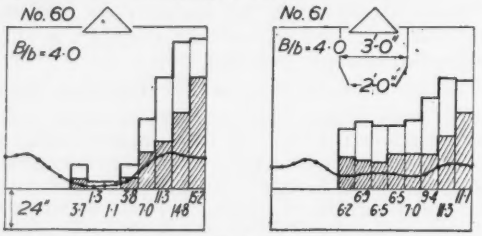


FIG. 12—Contours and size distribution of Nos. 60 and 61, Fig. 11, showing effect of deflection blades

In No. 67 the deflector blades occupy the whole of the width, representing a section through a ring or hood surrounding the bell. The spreading of the charge is here produced by varying the height of the open distributing bell; in the lowered position the deflector hood has little effect, but at alternate feeds the bell is raised a little and the deflector comes into operation. It is not difficult to arrange for such mechanical raising and lowering; a similar operation is carried out mechanically on one type of producer as a charging method and not as a deflecting process.

In all such cases it is clear that the first essential is to ensure that the initial charging mechanism is capable of sending *an excess* of material towards the perimeter of the producer in order to allow for the portion deflected back towards the centre. This is easily achieved when the charge is dropped symmetrically from a rotating drum on to a distributing bell, and these are the conditions simulated in the deflector experiments. The necessity for this precaution was seen in some experiments under industrial conditions (*see* page 71).

The movement of the bell involved in experiment 67 is equivalent to 6 in.; the 'hood' within which the bell would move could be part of the producer top, and a portion might well be armoured to withstand the impact of the fuel.

In this study of beds built up in 'static producers' one or two factors have not been discussed. For example, when successive feeds are introduced, the first arrives on a flat-topped piston whereas succeeding feeds descend upon a conical surface which gradually becomes broader. The distribution of successive feeds is therefore different. This is obvious from the bed shown in Fig. 6, where the successive feeds are alternately black and white. The present results are thus intended to be comparisons of the completed beds where the sum of the feeds is considered. The total amount charged and the amount per unit feed has been controlled throughout. It has also been found that 10–20-mesh material has a somewhat different path when leaving the bell, but the difference is not large. This is distinct from the difference in rolling behaviour on the fuel bed, which is of much greater significance.

SLICE MODELS OF THE MORGAN PRODUCER

In the Morgan producer the conventional 'bell and hopper' method of charging is discarded and an automatic charging mechanism is employed which includes a method of controlling the distribution by varying the slope of two or three intercepting blades commonly known as 'flappers.'

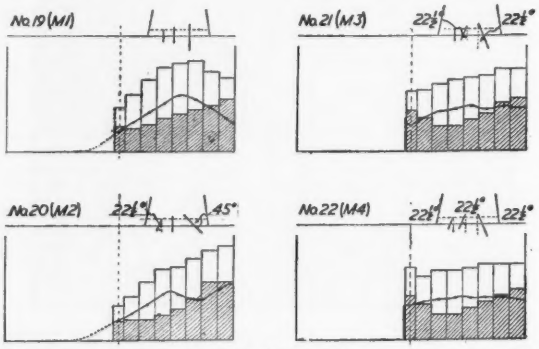


FIG. 13—Contours and size distribution results using first Morgan model; scale 1 : 24. Effect of adjustment of 'flapper angles'

A 1 : 24 scale model of a modern 11 ft. Morgan was made, incorporating three miniature adjustable flappers in its small-scale rotary feed.

Since it is a rotating producer, the Morgan feed aims at distributing the fuel over half the width only. In order to make any comparisons with the previous results for static producers, the contours produced in this model must therefore be visualized as having a mirror image on the left. Such contours covering the whole width of the producer would not occur in practice, due to the action of the leveller and because, in any case, no two radii fed are in a straight line so as to form a diameter, except by accident.

In order to have some measure of the extent to which the flappers are able to influence the distribution, a preliminary experiment was made in which all three were vertical and so exerting little, if any, effect. The result, allowing for duplication of the contour on the left, was not unlike that for a static bell-and-hopper charge using a rather small bell ; it showed a marked shortage at the wall and a large excess there of the coarse component. As in previous experiments the charge consisted of equal parts of 10–20-mesh coal and 40–60-mesh marble. The contour and size distribution are shown in Fig. 13, No. 19, in which the method of representation is as previously described ; the feed box and the flappers are drawn to scale.

The flappers were then tilted in an attempt to improve the distribution. In No. 20 (Fig. 13), it is seen that an adjustment of the outer flapper, as shown, greatly improves the conditions at the wall, increasing both the total amount and the proportion of fines : the latter is the result of the coarse component rolling away from the wall instead of towards it as in the previous case.

In both of these experiments a small proportion of the charge is seen to be beyond the centre line ; this happens in the actual Morgan producer, especially with sized coal, but since it occurs ultimately from all directions, this material should be credited to the half under examination. For this reason, in experiments 21 and 22, Fig. 13, a small shutter was used to prevent the material from rolling past the centre line. Unfortunately this leads to an exaggerated result for the quantity in the end slot. A more accurate method of correcting for this, by modifying the diagram, will be mentioned later (see Fig. 20).

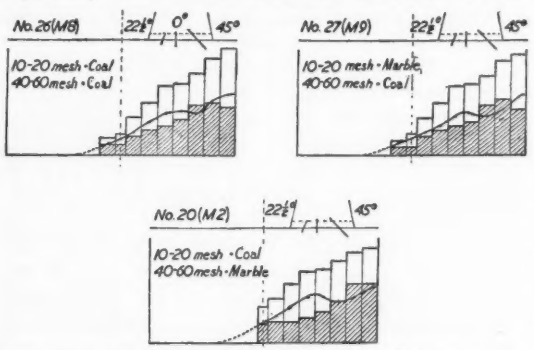


FIG. 14—Comparison of results obtained in a given experiment (*a*) using coal for both components ; (*b*) using marble for the coarser component, No. 27 ; (*c*) using marble for the finer component

These preliminary experiments show that the flappers can produce an appreciable effect upon the contour and the size distribution. This effect is at its maximum in these experiments, for the ash bed—actually a piston—was placed at its lowest position in order to determine this maximum.

In practice a fairly deep ash bed is always carried in Morgan producers, and the fuel bed is so near the feed box that if the flappers are tilted the material meets the fuel bed *at an appreciable angle* ; this means that the distribution is affected by the height of the bed which in turn depends upon the ash-bed level. Model experiments have shown that this effect is quite marked.

The effect of using 40–60-mesh marble instead of coal was examined with this model also. Density has little effect on particles in free flight, but in this model there is much more impact and rebound involved and the use of marble might now involve appreciable error. Figure 14 shows that there is no appreciable difference when the marble replaces either the coarse or the fine coal of a mixture.

The Morgan experiments so far described are to be regarded as preliminary trials. The 1 : 24 scale model was too small to provide sufficient material in each slot unless the charge was built up by continued feeding. It will be shown later that there are serious objections to this in Morgan models—in fact the scope of the *slice* model technique is, in the case of rotating producers, limited but still useful. In addition, the flappers of the first model were rather small for convenient and accurate adjustment.

As in the static experiments a second model was now made on twice the scale. The breadth was not actually doubled since there was no purpose in having a large empty portion on the left ; it was, instead, made 8 in. wide, $5\frac{1}{2}$ in. representing the charged half and $2\frac{1}{2}$ in. left to allow for rolling past the centre line. A movable piston was again used to represent the variable ash bed. The front-to-back dimension was more than doubled because it would then permit visual examination of rolling in a direction perpendicular to the radius. A view of the complete model is given in Fig. 15.

In the diagrams which follow, an outline of the model is drawn as usual, the piston surface

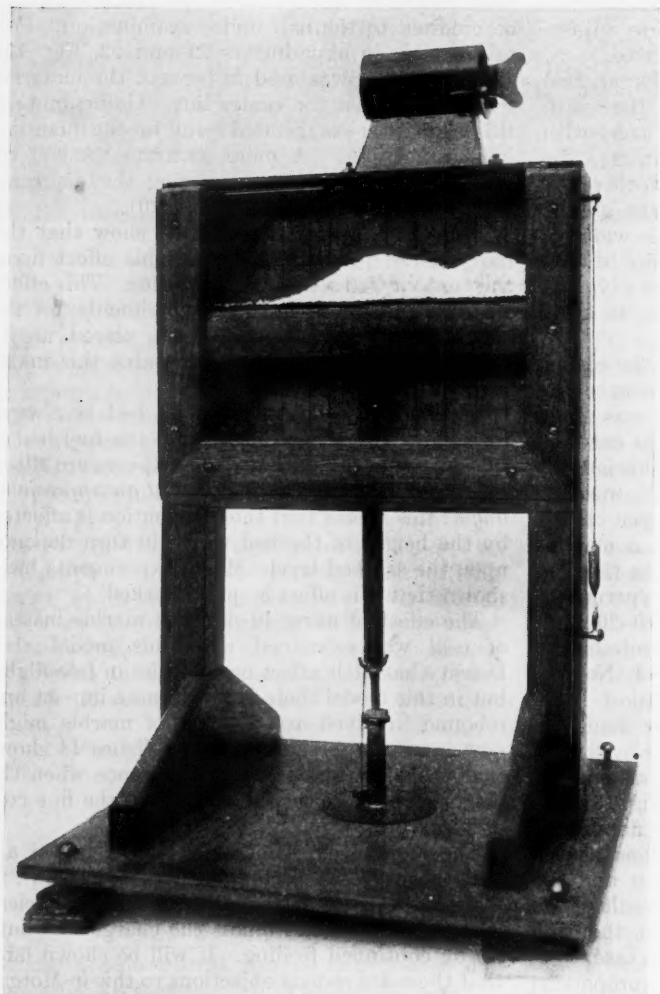


FIG. 15—View of second, larger, Morgan model; scale, 1 : 12

(ash bed) is shown by a horizontal line, and on this, rectangles are drawn of heights proportional to the quantity of material. In some cases figures are given in or below these rectangles to indicate the percentage of the total charge found in each position. The sizes of the components in a rectangle diminish upwards as before.

The following are some examples of the results obtained, after a preliminary test had shown that the characteristic form of No. 20, Figs. 13 and 14, is again produced but with a reduced height due to the greater depth of the new model.

Figure 16, Nos. 29 and 30

The variable here is the increased complexity and size ratio of the charge. No. 29 utilizes the usual 10–20 and 40–60-mesh material in equal proportions. In No. 30 the charge is made up from 20% of 0·15–0–10-in. coal, 30% of 10–20 mesh coal, and 50% of 60–100-mesh marble. Diagram No. 30 has drawn on

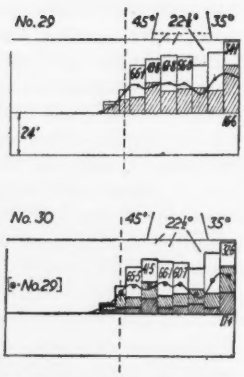


FIG. 16—Comparison of contour and size distribution in the Morgan model, using (*a*) 2-component, close size ratio charge, No. 29; (*b*) 3-component, wider size ratio charge, No. 30

it the points marking out the contour of No. 29; there is no significant difference between the two contours. In addition, the ratio of marble to coal in any position is strikingly similar in the two cases. This is not to say that the two beds are identical. The permeability of No. 30 would probably be less than that of No. 29 (due to the 60–100-mesh component) and would show more variation due to the 0·15–0·10-in. component.

Figure 17, Nos. 29, 32, 33, and 31

This series shows the effect of progressively changing the large end flapper angle on the amount and size ratio of the material at the wall—an important matter in Morgan operation. *Note that the steady increase in the size of the valley at the wall is accompanied by the gradual disappearance of the valley at the third position.*

Figure 18, Nos. 33, 34, 36, and 35

The 'no rolling' distribution produced in the

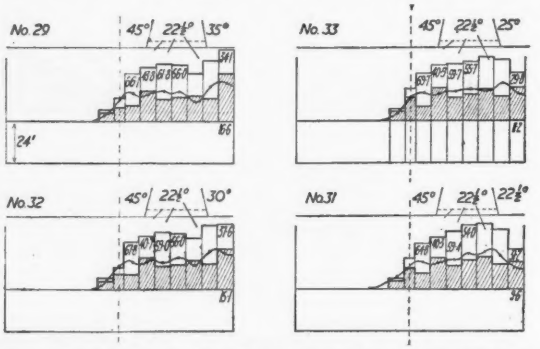


FIG. 17—Effect of tilt of large end flapper on contour and size distribution in the Morgan model

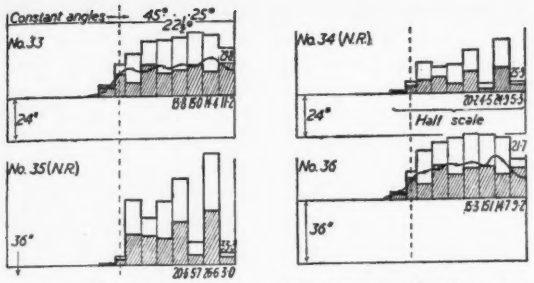


FIG. 18—Comparison of normal and ' no rolling ' results at ash-bed levels of 24 in. and 36 in. in the Morgan model. Flapper angles constant

Morgan is shown here for two ash-bed levels, 24 in. and 36 in., Nos. 34 and 35. The corresponding results with the usual rolling are also shown, Nos. 33 and 36. Comparison of these shows that an increase of 12 in. in ash-bed level, with fixed flapper angles, has a distinct effect upon the amount of material at the wall.

It is clear from these no-rolling experiments that the Morgan charging mechanism controls the distribution of the charge and avoids segregation to a far greater extent than is possible with the ordinary bell-and-hopper system. Its chief defect seems to be that it is impossible to place a good supply at the wall by increasing the tilt of the

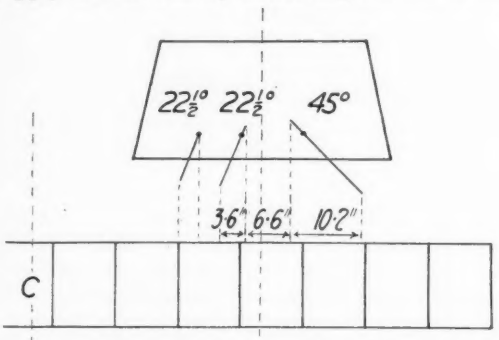


FIG. 19—Diagram showing shielding effect due to tilt of large end flapper in the Morgan model

large end flapper without simultaneously producing a marked valley at the position corresponding to the third slot (18–27 in. from the wall).

The interdependence of these two positions is easily seen in the photographs and may be explained by means of Fig. 19. This is a scale drawing of the feed box, the flappers, and the ' slots. ' For convenience the latter are shown immediately below the feed box. It is seen that with the large flapper at 45° in order to direct sufficient of the charge to the wall, a horizontal distance of 10·2 in. covering the third slot (9 in.) is shielded from any direct supply of material. This part of the bed receives its material by rolling from the zones on either side or by deflection from the central flapper when the latter is tilted towards the wall. It seems to be the exception to find the central flapper so tilted in practice.

Apart from this, the distribution along the radius may thus be described as good, and the size ratio is maintained reasonably constant. This is largely due to the fact that the charge reaches the bed in several distinct streams ; there is less dependence upon rolling, and hence less segregation. To obtain the best results it is obvious that full use should be made of the flappers as and when occasion demands.

CIRCULAR MODELS

It has already been indicated that the slice model of a static producer is regarded only as an approximation. It is clear that the whole producer

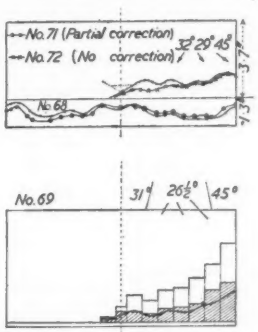


FIG. 20—Comparison of contours given by circular Morgan model (No. 68), uncorrected slice model (69 and 72), and partially corrected slice model (No. 71)

cannot be regarded as the summation of a number of such parallel-sided slices ; for this to be true the slice would need to be in the form of a double wedge. In other words the model does not fulfil the requirement of geometrical similarity.

The error involved is chiefly at the centre which, apparently, should build up faster than in the parallel-sided model. A given amount of material rolling towards the apex of a wedge would presumably build up higher and roll farther than that which occurs inside a parallel-sided slice. The final difference is actually less than would appear at first sight.

In the case of the Morgan producer, and in all such rotating producers, the slice type of model should only be used to demonstrate the distribution, with and without rolling, of a *single* feed.

Two methods have been employed for determining the difference between the slice result and the actual distribution. Both the ' static ' and the Morgan results have been compared with those obtained with completely circular models. The Morgan results have also been checked by inserting a glass plate vertically into the interior of the

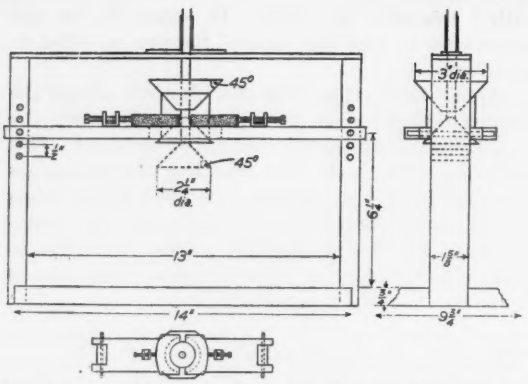


FIG. 21—Charging apparatus, etc., for round models of static producers

slice model so as to make its horizontal section almost a triangle. This is of course merely a partial correction and is not intended for regular use. It produces a progressive raising of the contour as the centre is approached. This is shown in the upper part of Fig. 20 by comparing Nos. 71 and 72. The diagram shows, in dotted lines, a correction for the material crossing the centre-line. The contour should thus proceed approximately along the horizontal dotted line, and when this is allowed for it is seen that the corrected contour No. 71 is not unlike the circular-model contour No. 68. Part of the difference is in any case due to the fact that there is a difference in ash-bed level of 1·3 in. (equivalent to 1·3 ft.) between the two experiments.

The static circular experiments were carried out with the apparatus shown in Fig. 21. This consists of a base-plate of 14 × 9¾ in., carrying a bridge overhead. Between the uprights of this bridge moves a cross-piece on which is mounted the charging mechanism, and which can be placed at any one of five vertical positions. The charging mechanism consists of a cylindrical hopper

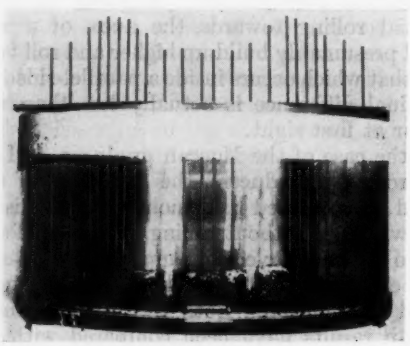


FIG. 22—Wire method for contour determination in circular models

clamped centrally by means of the shaped pads and adjusting screws shown ; the bottom of this hopper is closed by a movable cone of 2¼-in. dia. base, and a 3-in. dia. inverted cone is placed at the upper end of the hopper. The apex of this second hollow cone has been drilled out, and it is used to ensure symmetrical charging. The charging bell or cone is supported and operated by a rod which can be clamped with the bell closed or open, as shown in the diagram (clamping device not shown).

A cylindrical receiver of 9¼ in. diameter, is now placed centrally on the base-plate and sufficient of a charge made up of coal only, is dropped to produce a suitable measurable fuel bed. The contour clearly cannot now be photographed as with the slice model, but instead is measured and recorded graphically. The measurement of the contour, initially a laborious task, was later carried out as shown in Fig. 22. A wooden bridge carrying a number of steel wires is placed diametrically

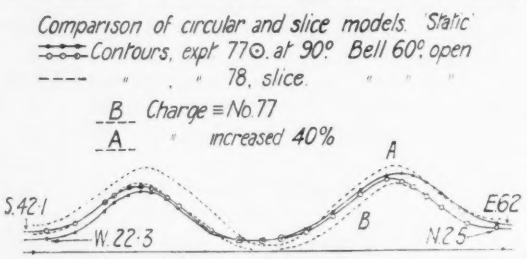


FIG. 23—Comparison of contours given by slice model and circular model of static hand-charged producer, bell base angle of 60°

over the receiver and the tips of the wires gently pushed into contact with the bed ; the bridge is then removed, laid on graph paper, and the contour drawn in. This is repeated at 90° as a check on the symmetry of charging.

In this way it has been shown that, for static models, the general form of the contour and the size distribution with both open and closed bell is as shown by the slice model, but that its results involve a greater deficiency at the centre than is actually the case. This is as would be expected.

Figure 23, experiments 77 and 78, provides a comparison between the contour results of a circular model and a slice model under approximately equivalent conditions. The symbol **O** is used in this diagram and elsewhere for circular-model results. A 60° bell was used in these experiments because a 45° cone was not then available. Two contours at 90° are given for the circular model and when these are averaged and an allowance is made for some lack of symmetry between them and the slice curve, the result is reasonably satisfactory except at the central portion. It is also shown that an increase of 40%

in the charge in the slice model does not correct this deficiency. The amounts charged into the two models are normally in the proportion of the area fed. The size distributions corresponding to these contours are shown in Fig. 24, and the agreement may be regarded as very good. The diagrams 75 and 76 on the left of the same Figure, are the results of a similar pair of experiments in which the amount of material used in No. 75 proved to be too little to give a reasonable corresponding amount in No. 76. They were therefore repeated in order to show up the central difference more clearly.

The amount sampled in each position across the diameter of the circular model was greater than the amount in the slots of the slice model. The rectangles are thus larger. This difference is due to the desire to sample a fairly large area of the bed, which has obvious advantages, especially in the Morgan circular experiments to

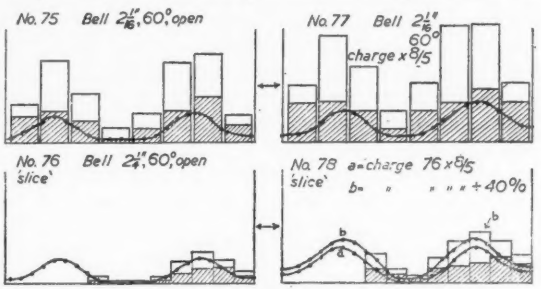


FIG. 24—Nos. 75 and 76 : Comparison of contours in circular and slice static models. Nos. 77 and 78 : As before, using increased quantities, bell base angle of 60°

be described later. The actual area was 2 × 1 in. as compared with 1 × ¾ in.

In Fig. 25, Nos. 80 and 81, the comparison between closed and open bell is repeated with a round model, using a 3 in. bell of 45° base angle. Experiments Nos. 82 and 83 in the same Figure show the same comparison with a 2¼-in. bell of 45° base angle. The additional supply at the wall with open bell is again seen.

The Morgan 'circular' experiments were not so simple to carry out and the comparison with the slice model results is not so easy to make. The rotation of the body while feeding is in progress must now be simulated.

The method of charging was to obtain a circular dish for the 'body,' place a bridge appreciably wider than the dish, along a diameter and resting on the top of the dish, and mount the rotary feeding mechanism from the slice model on this bridge. Immediately below was an internal cross-piece fitted at the ends with shoes curved to suit the radius of the dish. This was a tight fit inside the upper edge of the body, and carried a bolt

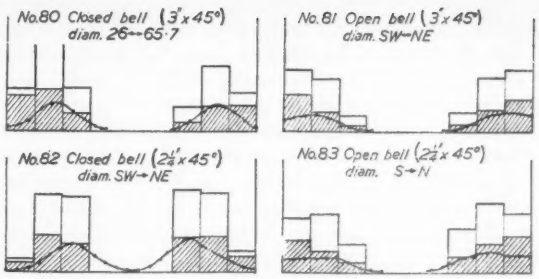

No.80 Closed bell (3"x45°) diam. 26→65·7
No.81 Open bell (3"x45°) diam. SW→NE
No.82 Closed bell (2¼"x45°) diam. SW→NE
No.83 Open bell (2¼"x45°) diam. S→N

FIG. 25—Comparison of closed bell and open bell charging using two bell sizes, both of 45° base angle

at its centre. This bolt passed through the centre of the bridge also, and the latter could thus be rotated smoothly, using the bolt as a centre. A frictional device controlled the ease of rotation of the bridge (*see* Fig. 26).

With this arrangement, instead of imitating the slow rotation of the producer body, the top, with its charging mechanism, was rotated in the opposite direction. The rim of the receiver was graduated so that with the aid of a stop-clock the speed of rotation of the bridge and also of the feeding drum could be controlled. Close control was actually needed only during the interval in which coal was dropping.

Since no provision is here made for raising and lowering the bridge and feeding mechanism, variation of ash-bed height is arranged by placing a layer of fine sand, of the required depth, at the bottom of the dish.

Each feed dropped into the body lies approximately along a radius and spreads itself over a width which depends upon the coarseness of the charge. There are gaps between these feeds on the first circuit, and the relative speeds of drum and body rotation were chosen so that on the second and third circuits the feeds fell in the spaces between the first series of feeds. In actual practice the leveller would tend to spread coal over these gaps between the feeds.

Figure 27 is a diagram, in plan and to scale, showing the spacing of the feeds inside the circular

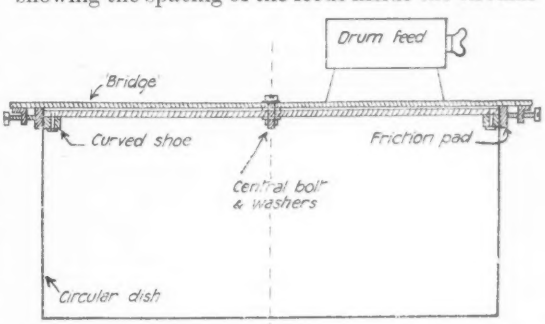


FIG. 26—Diagram of arrangement for charging in circular Morgan experiments

model, and showing also, the method of sampling. The first series of feeds fell along the dotted radii shown, occupying the width shown shaded ; two more complete circuits were needed in order to produce a bed sufficiently deep and uniform. The final result was such that all the feeds were approximately equidistant and the wave-like character of the bed was not too pronounced.

Sampling was by means of tinplate rectangular frames of 2 × 1 in. and 1½ in. deep, which were pushed downwards into the bed along a diameter ; the coal within each frame was collected and a size analysis made. A partial sampling at right-angles was also possible as shown in the diagram. The dimension of the sampling rectangle, 2 in., was chosen so that it would include sufficient of ridge and valley from the bed.

The statement made earlier that the Morgan slice model is really suitable only for the study of a unit feed may now be understood from this diagram. It is seen that the individual feeds overlap in a central zone which for the present experiments is contained within the inner circle shown. Hence the centre may appear to receive too small a proportion according to the slice model and yet in practice be very well supplied. This discrepancy may be seen in Fig. 20, by comparing No. 68, round model with No. 69, slice model, under the same conditions of flapper angles and fuel drop.

It should be noted that in the round model a diametrical contour need not be symmetrical, and in fact is not likely to be so. The reason is that it may begin on one side at the crest of a ridge, but on passing the centre point it may follow a slight valley. It is desirable in practice to see that the ratio of body speed to drum speed is not such that the feeds coincide in consecutive circuits, even though the leveller smooths out the bed later.

Levellers and Agitators

The experiments described are intended to compare the results produced by various methods and conditions of charging, and take no account of the subsequent effect of the Chapman agitator and the Morgan leveller. The better the initial distribution the less work, from that point of view, are such devices called upon to do. They do good work by consolidating the fuel bed and by preventing excessive agglomeration of caking coal, but as redistributors they may not achieve very much. The tendency is to push material around in circles and to cause much less movement along a radius. In the Morgan producer the leveller arm is not a radius except at one height of fuel bed (Fig. 28), and there is usually a reaction forcing the material towards or away from the wall. This has been observed inside the producer and the movement is not large. Further work with circular models should yield some data on this aspect of the subject.

Further work is also needed to demonstrate the distribution produced by the Chapman feed as

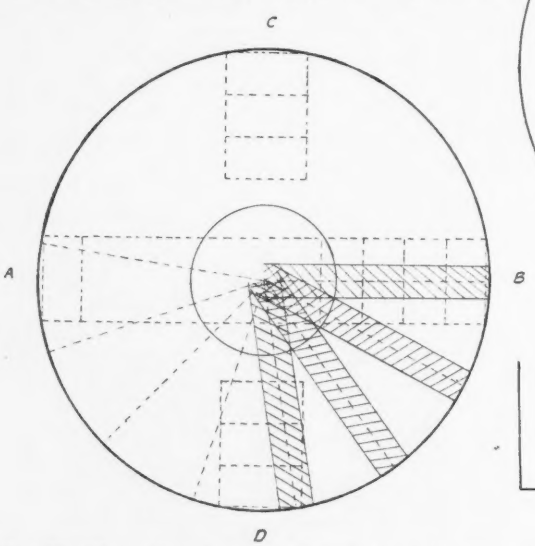


FIG. 27—Plan of location of unit Morgan feeds in circular model, showing spacing and overlapping. Sampling rectangles shown dotted

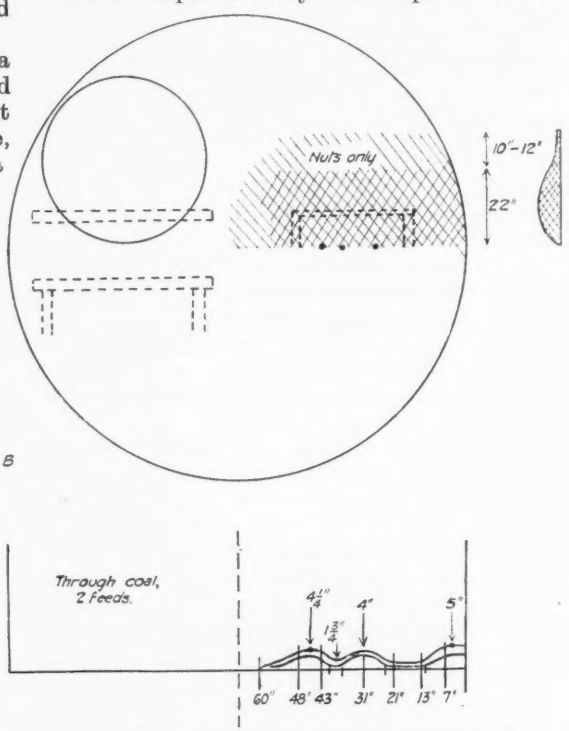


FIG. 28—Plan of distribution of fuel in actual Morgan producer. Below : diagram of contour produced by two feeds

actually employed, *i.e.*, feeding down a chute fixed at one side of the centre line. An attempt appears to have been made in this design to direct some of the charge to the far side of the bell, but the whole arrangement is much less symmetrical than that used in the ' open bell ' model experiments.

Works Tests

In all model experiments it is important to make comparison tests under actual industrial conditions.

The results of laboratory experiments on distribution in Morgan producers are confirmed to a gratifying degree by observations made inside an 11 ft. Morgan producer. Figure 28, lower diagram, shows horizontal and vertical measurements of two superimposed feeds of through coal. To prevent the bed rotating it was necessary to turn the rotary feed by hand. It is seen that the conditions were such (large flapper about 35° outwards, both smaller flappers about 23° inwards ; ash bed 32 in.) that an adequate supply to the walls is produced, but that this is accompanied by a marked valley at almost exactly the same position that a valley is indicated by the slice model under such conditions. The upper diagram shows the spread in two directions, both of the through coal and of sized coal, after several feeds. The dotted lines show the extreme positions of the leveller arm as the height of fuel bed varies. The extent to which the nuts roll towards the centre compared with that of smaller coal is surprisingly comparable with that found in the model for 10–20 and 40–60-mesh material. The error due to ' scale effect ' in such experiments on relative spreading of coarse and fine material is apparently very small. The photograph of the larger Morgan model, Fig. 15, shows a charge made up entirely of 10–20-mesh marble. The spread to the left is appreciably more than with a similar charge of 40–60-mesh. This is, of course, as would be expected. These comparisons are not dealt with in this paper.

Experiments have also been carried out with Morgan producers actually in operation. The statements made in the introduction concerning the influence of wall deficiency and segregation on the efficiency of the gasification process have been amply confirmed. Morgan producers showing marked ' hot-wall ' effect have been shown to produce very much worse gas there than at the central zone, the quality of the average gas made being considerably lowered as a result. These hot zones may be purely local and of relatively small width, but the bad gas made there is produced at a considerably higher rate, and the effect upon the average gas composition proportionately increased. It is quite common when such hot spots exist, to observe actual ' teetering ' of incandescent coke of appreciable size, which suggests a considerable local gas velocity. In addition, a comparatively narrow rim means an appreciable proportion of the total area. The following are some results obtained.

Morgan Producers—Works A

Four Morgan producers were examined. Gas was sampled from three positions at the perimeter from immediately above the fuel bed ; the analyses are given in Table I.

The gas from the centre of the fuel-bed surface was not examined in this case, but in the two cases where the offtake analysis is given, it would seem to be much better than the erratic results obtained at the perimeter. The fire bed looked much better at the centre and so did the gas emerging from the central poke hole. No results for CO are given owing to uncertainty regarding some of the figures obtained by the Orsat apparatus used in this works.

In all four producers the existence of very hot porous areas at the walls was evident.

Works B

Similar tests were carried out at this works, again on Morgan producers. The results are contained in Table II, and the following comments may be made.

The analysis marked with an asterisk is rather peculiar. The CO_2 + CO figure is rather high, at 33·8 ; the CH_4 is higher than usual but this is not due to the error, quite frequently met with, that the cuprous chloride absorption of CO is inefficient. In such cases the CO and the H_2 are both on the low side. That is certainly not the case here, and in any case, the rate of CO absorption was checked in all of these tests. The No. 2

Table I—*Gas Analysis from Morgan Producers—Works* A

Producer	Position 1		Position 2		Position 3		Offtake			
	CO_2, %	CO, %	CO_2, %	CO, %	CO_2, %	CO, %	CO_2, %	CO, %	CH_4, %	$\cdot_2$, %
No. 4	6·5	...	7·8	...	11·1	...	...	...	...	...
No. 3	9·1	...	...	...	11·8	...	...	...	...	...
No. 1	4·2	...	10·0	...	7·1	...	6·3	25·7	2·2	11·0
No. 2	3·8	...	4·0	...	8·9	...	6·2	24·0	2·8	12·0

TABLE II—*Gas Analysis from Morgan Producers—Works* B

Producer	Time of Sampling	Position 1			Position 2			Position 3			Centre			Offtake				
		CO_2, %	O_2, %	CO, %	CO_2, %	O_2, %	CO, %	CO_2, %	O_2, %	CO, %	CO_2, %	O_2, %	CO, %	CO_2, %	O_2, %	CO, %	CH_4, %	H_2, %
No. 6	...	11·3	0·8	9·0	9·1	0·1	21·3	9·8	...	20·0	7·4	0·1	25·3	9·3	0·1	21·0	...	...
No. 4	A.M.	13·8	0·3	12·6	...	...	...	17·0	0·3	3·3	...	...	...	...	...	...	...	...
								12·1	...	16·6	(A short distance away from 1st sample)							
No. 4	P.M.	15·6	0·1	7·1	10·6	0·5	10·9	1·5	(4·1+)	...	5·1	0·1	25·3	7·5	0·1	22·6	...	...
								14·6	0·4	5·9	(1 hr. later)							
No. 4	2 days later	...	...	...	...	...	...	10·9	0·3	16·9	(Midway between positions 3 and 1)							
No. 4	Next day	13·8	3·3	2·4	8·0	(?)	27·6	12·0	0·3	14·6	6·0	0·1	27·5	6·8	...	27·0	4·4	15·6*
No. 3	...	11·7	6·1 (?)	1·8	...	...	...	8·4	...	22·3	5·4	0·2	26·9	...	...	...	...	...

* See textual comments

position on the same day also had a high CO_2 result in view of the CO content. It is possible that the CO_2 in these two analyses is on the high side.

Most of the analyses were made with the Orsat type of apparatus and are of the corresponding degree of accuracy. No attempt has been made to apply a theoretical analysis to the figures.

It is clear that the mediocre offtake analysis in these producers is due to dilution of comparatively good gas by the very bad gas from the perimeter. The good offtake analysis marked with an asterisk was obtained after the large flapper had been tilted appreciably further in order to direct more coal to the walls. This had been done the previous day and the general condition of the producer appeared to be considerably improved. It is seen that good gas was then being made in one of the perimeter positions, while the poor gas at Nos. 1 and 3 positions was presumably small in amount.

These good analyses and the much superior results so often obtained from the centre, support the statement made at the outset that the coal supplied can yield good gas under the right conditions, but that these conditions are difficult to maintain under local circumstances.

In this works there appeared to be very little use made of the flappers. In most cases the large flapper was found to be almost vertical or at best, tilted by only a small amount. The poor results at the wall are no doubt largely the result of this, for much-improved results were obtained when the large flapper was tilted to a much greater extent.

The figure of (4·1 +) given for the percentage of oxygen in gas producer No. 4, P.M. (in Table II), means that the determination of oxygen was abandoned when it became obvious that a considerable amount of air was present due to the hole in the fire.

Works C

The Morgan producers at this works are of an earlier type, having two small flappers instead of the set of three in the more recent design. The model experiments thus do not apply to these machines but an examination of this type is interesting as a comparison.

The weakness at the wall is again present though to a small extent at these works and the gas made is very poor in some positions. It was noted that the results were satisfactory at the centre and at position 1 in all of the tests. The gas is rather high in CO_2 due to the high saturation temperature regularly maintained as a precaution against clinkering.

In all these works tests it should be noted that the positions described as Nos. 1, 2, and 3 are standard positions on the Morgan producer and are not chosen at random. There appears to be a tendency for the quality of the gas to be related to the sampling position, though there is too little data to make any conclusive statement. This is not quite so incredible as it may appear at first sight. The positions are related to the point at which ashing begins and ends, so that any peculiarity in the mechanical ashing of this type of producer may be reflected in the producer performance.

TABLE III—*Gas Analysis from Morgan Producers—Works* C

Producer	Time of Sampling	Position 2			Position 1			Position 3			Centre			Offtake				
		CO_2, %	O_2, %	CO, %	CO_2, %	O_2, %	CO, %	CO_2, %	O_2, %	CO, %	CO_2, %	O_2, %	CO, %	CO_2, %	O_2, %	CO, %	CH_4, %	H_2, %
C	A.M.	10·8	...	16·5	7·8	...	23·8	9·8	...	21·8	9·3	...	20·5	8·0	...	22·0	...	...
	P.M.	17·0	0·8	3·0	...	...	...	...	...	...	...	...	...	...	...	...	...	...
G	A.M.	13·3	0·8	13·0	8·8	0·2	22·0	10·8	...	18·3	8·5	...	18·3	7·8	...	21·2	2·3	13·4
	P.M.	11·0	...	18·0	7·5	...	23·8	...	...	...	...	...	...	...	...	...	...	...
C	A.M.	8·8	...	20·0	6·5	...	23·0	13·0	...	10·3	6·8	...	22·5	7·2	0·4	22·4	2·8	18·1

TABLE IV—*Distribution across a Static Producer—Works* A

Experiment	Wall					Centre					Wall
	1	2	3	4	5	6	6	5	4	3	2	1
I	0·27	1·21	1·76	5·95	12·7	29·3	19·5	18·2	5·0	2·97	2·43	0·88
II	0·14	0·56	1·13	2·86	7·9	30·8	26·5	13·1	4·1	7·6	5·0	0·42
III ...	3·65	5·75	6·23	5·85	10·8	18·9	13·4	5·8	3·76	8·55	11·15	6·0

Static Producer—Works A

Experiments with an industrial static producer fitted with a Noyes basket, confirm the statement made earlier that with such deflecting devices, . . . "*the first essential is to ensure that the initial charging mechanism is capable of sending an excess of material towards the perimeter of the producer in order to allow for the portion deflected back towards the centre.*" This condition is not satisfied by the usual bell-and-hopper charging systems, and the Noyes basket is then inclined to increase the fuel supply to the centre at the expense of an outer zone which is already deficient in fuel.

The figures quoted in Table IV were obtained by placing 12 boxes across a diameter of a static producer charged in this manner. The material caught in the boxes was distributed as indicated in Experiments I and II, the figures being percentages of the total along that diameter.

It is seen that the four boxes nearest the centre received 79·7 and 78·3% of the material in the first two tests, while the perimeter is obviously very poorly served. The distribution is, even so, broader than in similar producers without a Noyes basket, the centre being then impoverished as well. A modification of the basket later carried out, reduces the supply at the centre, but it is not possible to correct the deficiency at the wall. In practice the occurrence of rolling serves to equalize the bed as compared with the results given by a ' box test.'

A third test was carried out with the bell in the ' open ' position, other conditions being as in the above experiments, in order to throw the material farther towards the wall. The distribution was then as shown in Experiment III, Table IV. This represents a distinct improvement on the previous figures and is excellent confirmation of the model experiments. As stated, the basket needed modification so as to reduce its effect. Unfortunately no tests were carried out after the modification had been made.

Mechanical Producer W—Works D

The following is an account of a recent occurrence which serves as an interesting and instructive example of the useful information which may be gained by the use of producer models.

It should be noted that the producer was installed largely as an experiment and it was realised that modifications might have to be made in the light of its early performance.

The initial results were disappointing ; the fire blew so hot at the centre that it was put out for adjustments. The trouble was considered to be due, at least in part, to the blast-hood sending the blast too much to the centre and possibly too high up. The upper two caps were removed and a blank was fitted. On recommencing, the producer worked much better, making quite good

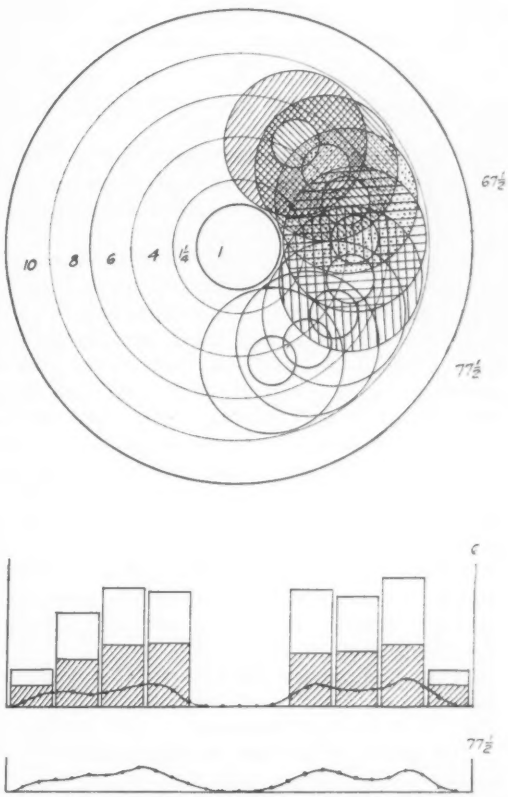


FIG. 29—Producer W, circular model, bell 1 ft. dia. ; scale, 1 : 12. Plan of feeds overlapping as producer rotates. Below : contours of fuel bed along two diameters

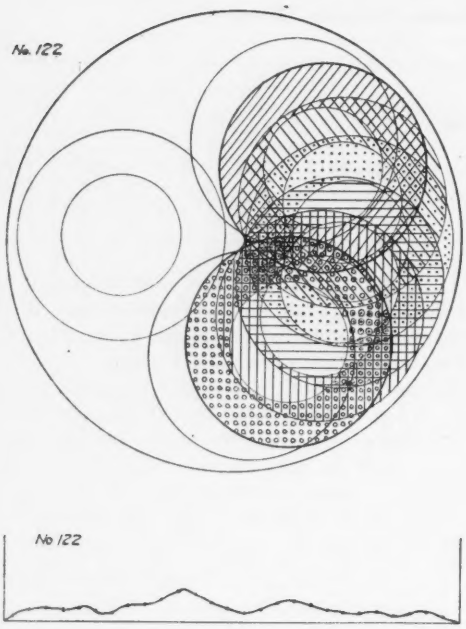


FIG. 30—Producer W, circular model. Plan of distribution when bell diameter is increased to $1\frac{3}{4}$ ft.

gas, but the centre was still definitely on the hot side.

At this stage the writer visited this works to see the producer in operation, and on examination of the producer drawings it was thought that the root of the trouble lay in bad distribution.

The producer is an 11-ft. rotating type with an automatic bell-and-hopper feeding mechanism situated midway between the centre and the wall of the producer. The bell is 1 ft. in diameter and it can be visualized as a 1-ft. bell serving a $5\frac{1}{2}$-ft. producer, *i.e.*, the half being charged at a given moment. A producer having a body/bell ratio of $5\frac{1}{2}$: 1 would, from the previous work (Fig. 10), have a marked deficiency at the walls and centre. In the present producer this means a deficiency at the wall, half-way along the radius, and again at the centre ; when this is repeated along the other half of the producer the deficiency at the centre of this producer is doubled. Since the producer rotates, the deficiency half-way along the radius does not persist.

These preliminary ideas were later confirmed by means of a new circular model and by a ' box test ' on the actual producer.

The results of the first model experiments are shown in Fig. 29. A unit feed produced a ring or annulus of coal on the bed, and its dimensions were taken. The producer rotation means that a number of feeds overlap the first feed and these are in turn overlapped by subsequent feeds. Having determined the dimensions of a single feed from the model experiment, and knowing the angle of rotation from the body speed, the upper part of Fig 29 was constructed. It is seen that under these conditions three feeds overlap the first, so that certain areas receive a contribution from four feeds. It is from this part of the diagram onwards that the final bed structure becomes visible. Each feed is marked in a particular way, and it is possible to identify the feeds arriving at a given spot. Note that the diagram is compiled from a number of unit feeds and takes no account of rolling.

The lower part of Fig. 29 shows the contour and size distribution along a diameter after a complete circuit in the model. The contour along another diameter is also shown. The charge was a 50 : 50 mixture of 10–20 and 40–60-mesh coal. As a result of rolling a little coal reaches the zones shown empty in the upper diagram.

As shown in Fig. 29, upper diagram, the effect of overlapping is greater towards the centre than at the perimeter, so that the position of maximum feeding is just outside the impoverished centre. This is confirmed by the contours of Fig. 29.

It is seen, therefore, that the distribution can only be described as unsatisfactory. The plan view given in Fig. 29 is divided into 1-ft. wide zones marked 10, 8, 6, 4, a 6-in. zone marked $1\frac{1}{4}$, and a circle of radius 1 ft. marked 1. These numbers represent the relative areas of these zones and it is seen that the maximum feeding is mainly into the zone of area 4, while the zone of area 10 at the perimeter receives nothing. In addition there is a circle at the centre, 2 ft. in diameter, receiving no coal.

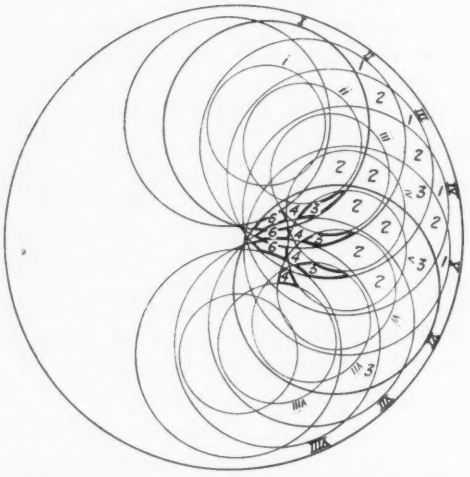


FIG. 31—Enlarged view of Fig. 30, showing number of feeds overlapping in various positions

These distribution results given by the model, were later amply confirmed by the results of a 'box test' carried out on this producer. The boxes were arranged along two diameters at right-angles; their dimensions varied slightly but the average size was 12 × 6 in., internal.

With the boxes in position as shown in Fig. 32, the producer was rotated and fuel was charged for three complete circuits. The results are given in Fig. 32 as lb./sq. ft., and it is seen that there is almost complete absence of coal at the centre and at the perimeter over distances very similar to those deduced from the model, *viz.*, a 1-ft. zone at the perimeter and a 2-ft. diameter circle at the centre. In addition, the position of maximum feeding is as deduced from Fig. 29.

No account is taken here of the redistribution which may or may not be produced by the leveller fitted to this machine. This suffers from the usual disadvantage that its action is largely limited to a circular path and there is insufficient displacement from centre to perimeter, or *vice versa*. In any case, the distribution of Fig. 29 calls for displacement in both of these directions, which is not possible with the usual straight-bar leveller. It would appear that a leveller with a circular mounting which could be rotated at a *small* angle if required, would be a useful aid in the control of fuel-bed contour. Such an arrangement might, of course, involve engineering difficulties, though if the necessary rigidity could be ensured it appears to be quite feasible.

From these results it would appear that a bigger bell would yield better results. This was examined by means of the model using a 1 ft. 9 in. bell, and Fig. 30 shows a plan of the result, together with a contour of the completed bed. The latter is seen to be considerably more uniform. The upper diagram shows on the left, unshaded, the size of a unit feed; it also indicates the increased number of feeds which now overlap, since the speed of rotation is not changed. The true final structure of the bed is not seen, as previously explained, until sufficient circles have been drawn to show the maximum overlapping which occurs. The two darker circles include such a complete series, of six feeds. The seventh feed overlaps only to a very small extent and for convenience is ignored. The result produced by the overlapping of the sixth feed is then repeated all round the

Box No.	Distribution, lb. sq. ft.
16	0
15	0
14	4·8
13	20·0
12	24·4
11	28·3
10	2·3

Box No.	17	18	19	20	21	22	23	24	9	0·4	25	26	27	28	29	30	31	32
Distribution, lb./sq. ft	0	0·1	4·3	13·5	23·6	23·9	25·6	1·8	8	0·4	2·46	25·6	20·6	21·1	19·3	14·5	4·1	0

Box No.	Distribution, lb. sq. ft.
7	0·9
6	24·4
5	25·8
4	22·9
3	9·9
2	1·5
1	0

FIG. 32—'Box test' of fuel distribution in mechanical Producer W

bed. This is easier to see in Fig. 31 in which the first and sixth of a series are more heavily marked and the number of feeds arriving at a given zone is indicated. The irregular areas which have been heavily outlined repeat in their respective positions as the bed rotates. Although rolling modifies this result the general distribution is clear and is ultimately of the contour shown in Fig. 30.

The ' ring ' of coal making up a unit feed is of the width shown in the diagrams but it is not, of course, a *flat* ring. There is a ridge at the centre and the feed tapers on each side. In other words, its cross-section is slightly humped. In using the term ' overlapping of a feed ' this must be borne in mind, so that overlapping varies in quantitative meaning according to which part of one feed overlaps which part of another.

Unfortunately the use of a bigger bell is not possible in this producer at present. During the box test previously referred to, the writer remained inside the producer, and it was seen that the cylindrical space within which the bell operates is of so small a diameter that even with the present bell the bottom edge of the surrounding surface interferes slightly with the free flight of the coal. It is thus not possible to check experiment 122 on the actual producer. Instead, the manufacturers' engineers ingeniously inserted a pair of deflectors to remedy the deficiencies shown in Fig. 29. These were found to achieve and even to exceed the desired result, and by adjusting the widths of the deflectors the distribution was clearly improved very considerably. This episode is considered to be a good example of the utility of such model experiments.

Conclusions

1. The hopper-and-bell system as usually used on static hand-charged producers, yields unsatisfactory results. Unless the bell is exceptionally large in proportion to the body there is a shortage of material at the wall accompanied by an undue proportion of the coarse material of the charge. This is a highly undesirable state of affairs. The centre receives fuel mainly by rolling, which is obviously a source of size segregation. Increasing the bell diameter to increase the supply to the perimeter accentuates the difficulty at the centre.

2. A ' distributing ' bell as used in automatic charging systems, deflects the material outwards to a much greater extent. A relatively small bell is capable of throwing an excess of material to the perimeter whence a proportion of the coarse constituent rolls back towards the centre leaving an excess of fines at the wall. The centre is now markedly deficient.

3. Much improved results may be obtained in static producers by the use of an auxiliary device for deflecting a portion of the charge inwards. It is advisable to arrange for an initial excess towards the perimeter to allow for the deflection inwards. Examples are given of beneficial results produced in this way. By the same method it may be arranged for coarse material to be deflected inwards, leaving an increased proportion of finer material towards the walls.

4. The actual result obtained with a given bell/body ratio is affected by ash-bed height, more material reaches the centre as the ash increases.

5. In Morgan producers the fuel distribution is markedly affected by the use made of the flappers. An adequate supply to the walls is easily ensured by using the outside, largest flapper : when this is tilted appreciably, however, a valley is produced about one third of the way to the centre. In all cases ash-bed height affects the result.

6. The mass distribution under ' no rolling ' conditions is much superior in the Morgan to that produced by bell-and-hopper charging. Size distribution is also much better under all conditions.

Acknowledgments

In concluding the account of works tests the author would like to express his appreciation of the facilities granted and labour provided for the carrying out of this work. Particularly valuable assistance has been obtained in this way from :

The Briton Ferry Steel Co., Ltd.
The Grovesend Steel & Tinplate Co., Ltd.
The Llanelly Steel Co. (1907), Ltd. and
Messrs. Richard Thomas & Baldwins, Ltd.,
Elba Steel Works, Gowerton.

This work was commenced as part of the Fuel programme of the South Wales Siemens Steel Research Association, and is being continued under the Steel Making Division of the British Iron and Steel Research Association.

The first part of this work, using 1 : 24 scale models, *i.e.*, up to experiment No. 27, was carried out at the Imperial College of Science and Technology, South Kensington, London, under Dr. H. L. Saunders, by whom the writer was initiated into the ' slice model ' technique. Acknowledgement is made of his unfailing interest and assistance during this period.

The work has since been continued at University College, Swansea, and the author has greatly appreciated the interest shown in this work, and the continual support given by Mr. Luther Phillips, Head of Swansea Laboratories of the British Iron and Steel Research Association.

A Photo-Electric Pyrometer for a Small High-Frequency Induction Furnace*

By T. Land, M.A., F.Inst.P.,† and H. Lund, B.Sc.†

SYNOPSIS

A simple pyrometer is described which uses a barrier-layer-type photo-electric cell and which has been found to be valuable in measuring the temperature of molten permanent-magnet alloys in a small high-frequency induction furnace. The conditions from the pyrometric point of view are reasonable in this particular instance, and the pyrometer will measure the true temperature of the charge within ± 10° *C.* (± 18° *F.*) *for certain alloys.*

INTRODUCTION

A SMALL high-frequency induction furnace is in use in the foundry at the works with which the authors are connected, for melting permanent-magnet alloys, chiefly of the Alnico and Alcomax types. Immersion pyrometers utilizing platinum–rhodium thermocouples have been in regular use on this furnace for some years. However, on account of the small capacity of the furnace (100 lb.), large rates of temperature change frequently occur, and it is most desirable to have some means of continuous indication of the temperature of the molten metal.

It was found to be impracticable to employ any continuously immersed thermocouple, but it seemed reasonable to try a photo-electric pyrometer focused on the metal surface.

The photo-electric pyrometer described below was installed, and it has been in continuous use for about two years. The results of observations with this pyrometer under works conditions are reported in the latter part of this paper.

THE PYROMETER

The complete pyrometer equipment is illustrated in Fig. 1, and a simplified drawing showing the construction of the instrument is given in Fig. 2. The location of the stops is shown in Fig. 3. The 2·5-cm. dia. selenium barrier-layer photo-electric cell and the 1·0-cm. aperture removable cell stop are held in an insulated holder at one end of a steel tube. A simple lens of 30 cm. focal length, and a 4·0-cm. aperture lens stop are held in the other end of the tube, so that the distance between the two stops is 60 cm. The cell holder is covered with a cap to exclude dust, and the inexpensive lens can easily be replaced if accidentally splashed with molten metal. Two extra stops are positioned inside the tube to eliminate stray reflections from the sides, which would otherwise lead to errors (Fig. 3).

FIG. 1—General view of the pyrometer, indicator, and shunt resistance

* Paper No. SM/AB/2/46 of the Pyrometry Sub-Committee of the Steelmaking Division of the British Iron and Steel Research Association, received 12th September, 1946. The views expressed are the authors' and are not necessarily endorsed by the Sub-Committee as a body.

† Research Department, Messrs. William Jessop and Sons, Ltd., Sheffield.

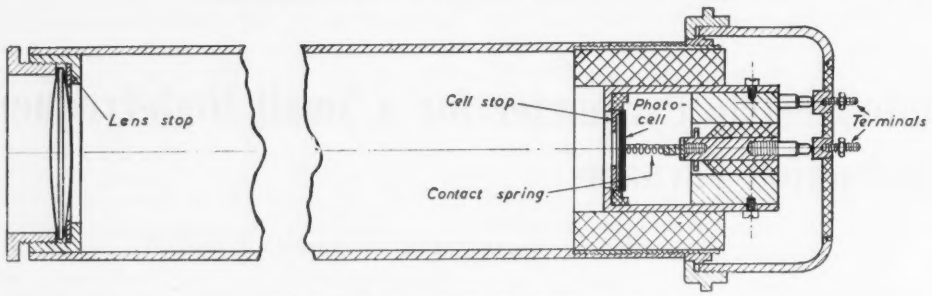


FIG. 2—Construction of the pyrometer

The lens focuses a small patch of the metal surface on to the photo-electric cell, the output current from the cell being measured by a micro-ammeter of 500-ohm internal resistance, giving a full-scale deflection with 15 micro-amp. The meter is calibrated directly in degrees Centigrade and is provided with a variable shunt resistance (Fig. 4),

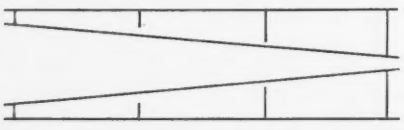


FIG. 3—Location of stops in the pyrometer

which allows the sensitivity of the measuring circuit to be varied. By adjusting the variable resistance the meter can be made to indicate the true temperature of the metal surface for spectral

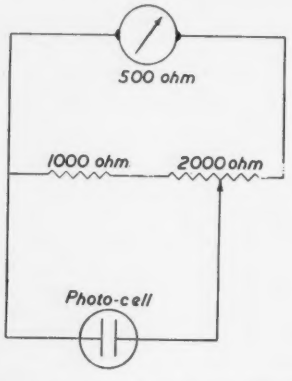


FIG 4—Circuit diagram of the pyrometer

emissivities* varying from 0·33 to 1·0. A dial graduated in terms of emissivity is fitted to the variable resistance (Fig. 5).

The pyrometer and the meter and shunt resistance are mounted on stands bolted to the furnace casing, and no external connections to the mains supply, water, or compressed air are necessary. The pyrometer is pivoted so that it can readily be swung away from the furnace during charging or when there is special danger of splashing the lens.

Calibration

The design of photo-electric pyrometers has been fully discussed by Land.† The dimensions of the lens and cell stops were calculated on the basis of this work, and the pyrometer was finally calibrated against a tungsten-ribbon-filament lamp, the brightness temperature of which was accurately known in terms of lamp current. For calibration purposes the pyrometer was sighted on a magnified virtual image of the lamp filament, with the emissivity dial set at 1·00. Due allowance was made for the difference in effective wavelength of the photo-electric cell and the disappearing-filament pyrometer used to calibrate the lamp, as proposed by Land (*loc. cit.*). The absolute accuracy obtainable by this method of calibration is probably about ± 7° C. (± 13° F.).

Observations

The pyrometer was observed in use on the furnace over periods of two or three weeks, at intervals of a few months. The readings of the photo-electric pyrometer were compared with the true temperature of the charge as measured by the quick-immersion thermocouple, without interfering with the furnace routine any more than was necessary.

The furnace is chiefly used for melting permanent-magnet alloys of the Alnico and Alcomax types, and the observations reported refer to these alloys. These give a very satisfactory uniform surface tolerably free from smoke and fumes and have no thick layer of slag, but only a thin film of oxide. The maintenance of a good

* The photo-cell current is chiefly determined by the radiation in the wavelength range 0·5–0·7 micron; the relevant emissivity is therefore the mean spectral emissivity over this range.

† *Journal of the Iron and Steel Institute*, 1944, No. I, p. 481P.

surface depends, of course, on the care of the furnace operator.

The true temperature of the molten metal was measured with a platinum/platinum–13% rhodium thermocouple, lightly sheathed in silica in the usual way and used in conjunction with a Tinsley amplifier and recorder. The recorder was frequently checked against a potential divider and potentiometer, to ensure maximum instrumental precision.

The comparison between the two methods of measurement was made as follows. The shunt resistance was first set at emissivity 1·00, so that the pyrometer measured the brightness temperature of the metal. The emissivity of the surface was then calculated by comparing the brightness temperature with the true temperature. After taking a number of readings in this way, the dial was set to correspond to the average value of the emissivities so calculated, and a series of observations extending over two or three weeks was taken with the dial in this position.

Fig. 6 shows the distribution of these readings for one series of observations. It will be seen that out of 28 readings, twenty gave equal temperature readings within ± 5° C. (± 9° F.) on the two types of pyrometer, and in only one instance is the discrepancy greater than 11° C. (20° F.). In this instance it is fairly certain that the error was in the immersion reading and not in the photo-electric pyrometer. It will be seen that, within the limits of experimental error, the emissivities of both alloys have a constant value (which was found to be 0·72 ± 0·05) over the range 1500–1630° C. (2730–2965° F.) covered by the experiment.

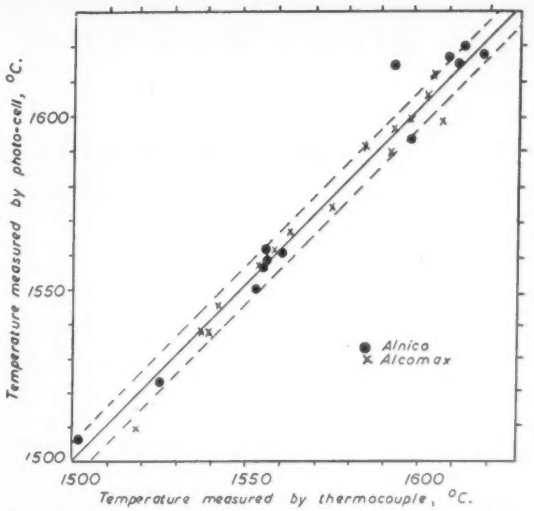


FIG. 6—Photo-electric-pyrometer and thermocouple readings. The broken lines indicate range of agreement within 5° C. (9° F.)

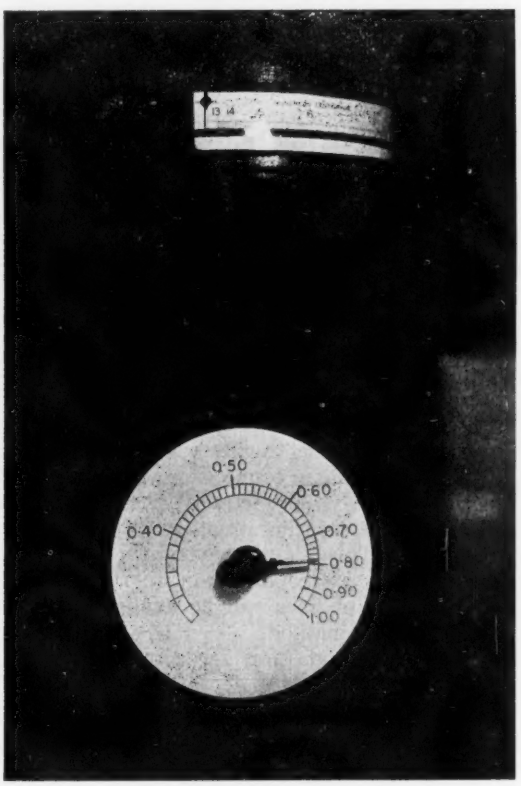


FIG. 5—The temperature indicator and dial calibrated in emissivity. When the pointer is set to the emissivity of the metal surface, the indicator shows the true temperature of the metal

It should be emphasized that the accuracy of such a pyrometer depends entirely on the nature of the metal surface. The particular alloys most usually melted in this furnace happen to give extremely good surface conditions, and a few results which have been obtained on other alloys gave a lower order of precision.

CONCLUSIONS

The pyrometer itself is very simple and the maintenance required is almost negligible, being confined to brushing away accumulated dust and the occasional replacement of the photo-electric cell or a badly splashed lens. With reasonable care on the part of the furnace operator the pyrometer will indicate the true temperature of the furnace, with considerable precision for alloys of the Alnico and Alcomax types.

ACKNOWLEDGMENT

The authors wish to record their thanks to Mr. D. A. Oliver, M.Sc., F.I.M., F.Inst.P., Director of Research, Messrs. William Jessop and Sons, Ltd., for his interest in the work.

The Direct Reading of Spectral-Line Intensities*

A REVIEW OF SOME RECENT APPLICATIONS TO SPECTROGRAPHIC ANALYSIS

By J. H. Oldfield†

SYNOPSIS

In spectrographic analysis direct-reading methods employ a photo-tube instead of a photographic plate for recording spectral-line intensities. The line may be scanned by a moving tube, or the tube positioned behind an exit slit. Counters, or condensers charged by the photo-currents, are used to measure the light intensity, a comparison being made between a standard line and a line of the element being determined. Increased sensitivity can be obtained by amplifying devices, and intensity ratios of a high order can be measured. A commercial model, the Quantometer, consists of source, dispersing, and recording units operating as one instrument. It is claimed that the method is likely to find its greatest use in industrial control processes.

In spectrographic analysis the errors associated with the photographic plate have long been recognized, and various methods have been adopted to minimize them. These methods, however, have necessarily lengthened and complicated spectrographic analysis. Consequently for some years attempts have been made to employ direct-reading methods by substituting a photo-multiplier tube for the photographic plate. The photo-tube is placed in a position in which the spectral line is incident upon the cathode, and thus, by using appropriate amplifiers and computing devices, a measure of the incident radiation can be obtained.

Early attempts at direct reading were unsuccessful because of the instability of spectrographic excitation sources and the low sensitivity of the photo-tubes then available. The literature of direct reading deals with the successive attempts to overcome these difficulties, and the latest publications indicate that these have been largely successful and that direct reading is now being employed in the routine analysis of certain types of alloys. A commercial model of a direct-reading instrument has, in fact, now become available. It has been called the Quantometer.[5]

Two methods are employed for rendering the spectral-line radiation incident upon the cathode of the photo-multiplier tube. One method[2] is to move the tube across, and thereby scan the spectral region to be measured; the other is to have fixed photo-tubes positioned behind exit slits which are placed in the optical path of the spectral-line radiation.[1, 3, 4] The method using the fixed slits is the more desirable one, provided that the limitations set by the dispersing power of the spectrograph can be overcome. In one of the latest devices[4] a system of lenses and mirrors is used to direct the spectral radiation to a position in which a photo-tube can be conveniently accommodated. With such an arrangement the intensities of lines which are close together in the wavelength scale can be measured. When fixed photo-tubes are used it is necessary to maintain thermostatic control of the spectrograph in order to prevent wandering of the incident radiation, which would occur with a change in refractive index of the optical components with a change in temperature.

A manifold increase in sensitivity can be obtained by the use of amplifying circuits. An amplification of 400 times is quoted in the literature.[2] It is claimed that anything which can be photographed within two hours can be measured photo-electrically without trouble, this claim being made in connection with the scanning method.[2] It is also stated[2] that there is no difficulty in measuring intensity ratios as high as 40,000 : 1. This is quite beyond the scope of the photographic plate, and indicates that a much wider choice of lines will be available with the direct-reading method.

Bridge methods for recording the relative

* Paper *MG/DD*/1/46 submitted by the Spectroscopic Sub-Committee of the Methods of Analysis Committee of the British Iron and Steel Research Association (Metallurgy Division), received 28th October, 1946. The views expressed are the author's and are not necessarily endorsed by the Sub-Committee as a body.

† Bragg Laboratory, Sheffield.

intensity of two spectral lines have been employed and counters have been used giving integrated line intensities.[1] A novel method[4] integrates the line intensity over a sparking period of 20 sec. by storing the photo-currents in condensers. Direct-current amplifiers measure the stored charges and the results are recorded on electrical marking paper. The lengths of the lines give a measure of the time interval required for the condensers to discharge, and hence their lengths are related to the concentration of the element in the sample which is being analysed. The integration of the light intensity is a marked step forward in direct-reading technique as spasmodic changes occurring in the light source had previously proved a serious drawback.

The list of references given at the end of the paper constitutes a survey of the more recent experimental work which has been done in attempting to apply the direct-reading method to spectrographic analysis.

In attempting to assess the present position and future possibilities of the direct-reading method, it is interesting and significant to note with what thoroughness disadvantages quoted in the earlier papers have been successfully overcome in the later ones.

The following details represent some of the more salient facts taken from these publications. They are intended to serve as an indication of the present status of the direct-reading method; the numbers correspond to the references :

(1) Direct reading is four times as fast as present photographic methods. This includes the time of sample preparation. With the controlled multi-source unit as the excitation unit, it should be possible to estimate copper, silicon, magnesium, nickel, and manganese in aluminium down to the range 0·001–0·01%, and iron, tin, zinc, molybdenum, and lead in aluminium down to the range 0·01–0·1%. Direct-reading methods should be applicable to steel analysis provided that contents of over 0·10% are being considered. If in photographic methods results of the order of 2% inaccuracy can be expected, then those from direct reading might be as high as 4%.

(2) The same resolving power as that obtained with the photographic method can be obtained with the direct-reading technique, and photo-tubes can be considered to cover a wavelength range equal to that of the photographic plate.

The equipment can be used equally well for photographic and direct-reading techniques, and can be converted from one to the other in a few seconds.

It is probable that the method will be less suitable for qualitative analysis, where it may be necessary to study the whole of the emitted spectrum, than for the quantitative analysis of specific elements. It will find its greatest use in rapid industrial control processes.

(3) Analysis was made of magnesium castings, and it is considered that two analysts can make 100 determinations per hour on foundry samples.

Reproducibility tests on aluminium in magnesium alloy were made. The maximum deviation for an alloy containing 5·9% of aluminium was 2·5% and for 8·7% of aluminium it was 1·5%. It was found that for aluminium, zinc, and manganese the average deviation between the photo-tubes and photographic methods was similar to that between the spectrographic and the wet chemical methods.

(4) The direct-reading spectrometer has been in use for a year in connection with the analysis of magnesium alloys. Samples are run concurrently at the rate of 4,000 a month, representing 20,000 determinations.

The results are equal to, and in some cases superior to, those obtained with photographic methods.

The operation of the instrument is automatic, and the record on the paper strip, from which the analysis for seven elements can be read off, is obtained within 40 sec. from loading the sample into the clamp. The standard deviations for 200 runs over a six-day period were as follows : Aluminium (at 3%), 2·38 ; calcium (at 0·18%), 3·07 ; zinc (at 1%), 1·92.

(5 and 6) The Quantometer (manufactured by Applied Research Laboratories, Detroit, Michigan, U.S.A.) consists of three units, a source unit providing a powerful spark to excite the sample, a spectrometer for dispersing the light into a spectrum, and a recording console where the analysis in terms of percentage content is recorded.

It is stated that eleven elements can be determined in 45 sec., and that the accuracy is superior to ordinary photographic methods. The lower limit of detectability requires three times the concentration required by the best spectrographic methods. It is claimed[6] that an accuracy of 1% can be obtained on certain alloying elements in some low-alloy steels.

Two types of gratings, both having a radius of curvature of 150 cm., can be used with the spectrometer. One gives a dispersion of approximately 7 A./mm. ; the other, a dispersion 50% greater than this.

Twelve multiplier tubes can be accommodated in the recording unit. One records the intensity of the chosen standard reference line, whilst the others are available for the spectral lines of the elements to be determined. The photo-tube currents are amplified and passed on to the receiving consoles.

The final results are furnished by integrating

recorders which drive 50-in. tapes on which percentage figures are printed. The results appear at little windows on the console and after being noted, the tapes are restored to the original position by pressing a button. The sensitivity of each recorder is adjusted by sparking a standard sample of known content.

It is possible to arrange the receivers in two or three independent groups, so that two or three different types of alloys can be analysed.

Summary

It is evident from the information quoted above that direct-reading methods have already advanced sufficiently far to replace the photographic method for certain types of spectrographic analysis. It should be pointed out, however, that most of the work on direct-reading methods has been carried out with grating spectrographs of normal or high dispersion. In conclusion, it would appear that the chief disadvantages of the direct-reading as compared with the photographic method are:

(*a*) The direct-reading method requires a more stabilized source.

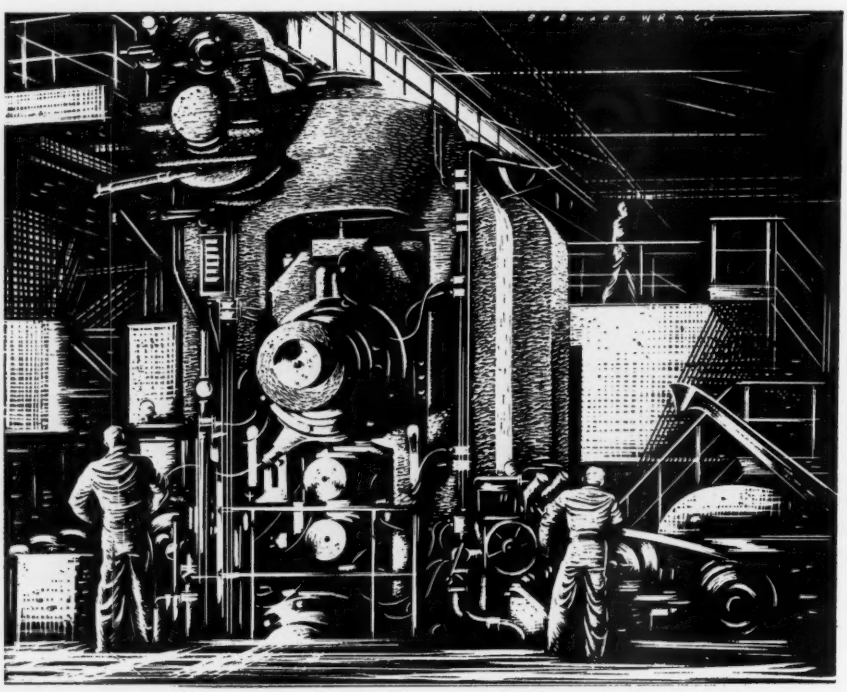
(*b*) The photo-tubes have highly individual characteristics, consequently the replacement of a tube is likely to necessitate a complete revision of calibration curves where these are employed.

(*c*) A complete permanent record of spectral emission of the source is not easily obtained; hence, as has already been stated, the method is not suitable for the qualitative analysis of unknown samples.

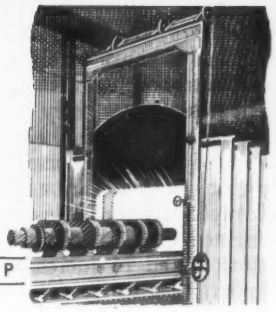
Subsequent progress in the direct-reading method, and its applicability to spectrographic problems in general, will largely depend upon the manner in which these disadvantages are overcome.

REFERENCES

1. M. F. Hasler and H. W. Dietert: *Journal of the Optical Society of America*, 1944, vol. 34, No. 12, p. 751.
2. G. H. Dieke and H. M. Crosswhite: *Ibid.*, 1945, vol. 35, No. 7, p. 471.
3. G. Nahstall and F. R. Bryan: *Ibid.*, 1945, vol. 35, No. 10, p. 646.
4. J. L. Saunderson, V. J. Caldecourt, and E. W. Peterson: *Ibid.*, 1945, vol. 35, No. 11, p. 681.
5. R. H. Muller: *Industrial and Engineering Chemistry (Analytical Edition)*, 1946, vol. 18, August (Advt. Sect.), p. 23.
6. M. F. Hasler, J. W. Kemp, and H. W. Dietert: *American Society for Testing Materials, Bulletin No.* 139, p. 22.



IRON AND STEELWORKS ENGINEERING



THE IRON AND STEEL ENGINEERS GROUP

THE IRON AND STEEL ENGINEERS GROUP

FOURTH MEETING

THE FOURTH MEETING OF THE IRON AND STEEL ENGINEERS GROUP of the Iron and Steel Institute will be held at the Offices of the Institute, 4, Grosvenor Gardens, London, S.W.1, on Wednesday, 11th June, 1947, when the three following papers on Power Generation for Iron and Steel Works will be presented for discussion.

The Discussion of the papers will be published in a future issue of the Journal.

Steam Turbines for Iron and Steel Works*

By I. V. Robinson, Wh.Sc., M.Inst.C.E., M.I.Mech.E.†

THE British steam turbine builders, members of the Turbine Section of the British Electrical and Allied Manufacturers' Association, on whose behalf this paper is presented, welcome this opportunity of placing before engineers who are concerned with the economic generation of steam and power in iron and steel works, some notes on the various means which have been instrumental in attaining the present efficient operation of the central power stations used for the supply of electricity.

In these power stations it is natural that very considerable attention has been paid to fuel or heat economy, as the cost of fuel is the major item in the total cost of generating electricity, *i.e.*, excluding transmission and distribution.

It is not suggested that it is possible or desirable to utilize, in power stations associated with iron and steel works, all the latest practices and developments which are usual in the larger public-utility power stations.

The object of this paper is to indicate what may be the ultimate developments in power stations in iron and steel works, all of which, however, it may not be possible to adopt when modifying existing works.

The circumstances in different works may vary considerably, so that a development which is quite suitable and economical for one works might be the reverse for others. It will be necessary for each case to be judged on its merits and for the engineers themselves to decide to what extent they can follow the lead set by the large-power-station engineers.

Pressure and Temperature in Utility Stations

In the early days of central-power-station practice a 3000-kW. set was regarded as a large unit, and a steam pressure of 200 lb./sq. in. with a superheat of 200° F., corresponding to a total temperature of 588° F., was considered good

*Received 17th March, 1947.

†The British Electrical and Allied Manufacturers' Association.

practice. In those days the vacuum at the turbine exhaust rarely exceeded 28 in. Steam turbines working with surface condensing plants lent themselves very conveniently to accurate determination of their performance, hence it became almost universal practice to test the steam consumption at various loads. The natural rivalry between different firms, and also between different engineers each responsible for his own power station, led to increases in the steam pressure and temperature. There was, also, an improvement in the design of condensers and particularly of the air extractors, so that wherever the water temperature was not in excess of say, 58°–60° F. a vacuum of 29 in. became standard.

The steam pressure rose gradually until now 600 lb./sq. in. (gauge) and 850° F. at the turbine stop valve are recognized as standard conditions for a 30,000-kW. set. For a 50,000-kW. set, the usual pressure has increased to 900 lb./sq. in. (gauge) and the temperature to 900° or 925° F. There are, however, many turbines of 50,000 and 60,000 kW. installed or under construction, for pressures up to 1350 lb./sq. in., and in one case 1900 lb./sq.in., with a steam temperature of 925°–950° F.

For units of 20,000 kW. the present standard practice is to use steam at a pressure of 400 lb./sq. in. with a total temperature of 800°. Usually, units of this size are installed in stations which are only intended to work on one or two shifts per day, each of 8 hr., and, with the shorter running hours higher conditions have not proved to be as economical as the lower ones.

The efficiency of the steam cycle in public-utility power stations has been increased, by what is termed a regenerative system. In this system, steam is extracted from the turbines at several points during expansion and used for heating the feed water to a temperature varying with the pressure, but which may, with the highest pressures, reach 390°–440° F.

It is not suggested that, for the turbines used in iron and steel works, the same high operating conditions can be used, due mainly to the fact that the average size of unit in the power stations of iron and steel works is very much smaller than any unit which is now generally used for public-utility stations.

If attempts were made to use very high pressures on small machines it would involve very heavy scantlings, and with the best possible design there would be undue leakage past the shorter high-pressure blading owing to the greatly increased density of the steam. Small turbines cannot fully utilize the advantage of very high pressures and temperatures. There is, therefore, an optimum pressure for machines of different capacities, and it is doubtful whether the largest condensing turbine which at present appears likely to be installed in most iron and steel works, would have a capacity in excess of 6000–10,000 kW., and the maximum pressure and temperature would probably be 400 lb./sq. in. and 750°–800° F.

Pressure and Temperature of Steam in Iron and Steel Works

Information has been received from various turbine builders, regarding the steam conditions for which they are now constructing plants for use in various iron and steel works, and it is found that only three units are at present under construction for pressures of 375 lb./sq. in. or upwards, the maximum being 420 lb./sq. in. The majority of them are still designed for pressures of under 200 lb./sq. in. Some of these units designed for low steam pressures have capacities as great as 4000 kW.

One turbine builder states that, according to their records, they have supplied to iron and steel works 68 turbines with an aggregate capacity of 150,000 kW., and of this number 21 were of the mixed-pressure type and 47 straight-condensing machines. Of these latter machines only 2 were for pressures of 400 lb. or higher, 4 for pressures between 200 and 400 lb., and 41 for pressures below 200 lb. The steam temperature did not exceed 750° F. Doubtless, these pressures have been determined according to the availability of existing boiler plant, possibly of the shell type, but it does seem that advantage should have been taken of a substantial increase in plant capacity to adopt entirely new pressures. If this had been done the new turbines could have been provided with a tapping point by means of which steam could have been passed out at a pressure corresponding to that of the old boiler plant, so that the new boilers could, by using the high-pressure portion of the turbines as a reducing valve, supplement any deficiency in the quantity of low-pressure steam available.

There is, however, one ironworks in the United Kingdom which has had large turbines working at a pressure of 1200 lb./sq. in. for many years, and from all reports that plant is running very satisfactorily. They have maintained their supply with practically no stand-by plant, such as a public-utility machine working an isolated station would consider essential.

Extraction Turbines

One marked improvement in the performance of industrial turbines, and of which the use is still increasing, is the pass-out or extraction steam turbine. In this, a portion of the steam, after expanding from the initial operating condition to

some predetermined pressure, is extracted from the turbine and led to other parts of the plant where it is required for process work. The steam not extracted for process work passes through the low-pressure portion of the turbine to the condenser. This type of machine has been used very largely in paper mills, dyeworks, laundries, food-preparation plants, and many other types of industry where steam at a relatively low pressure is required, either for heating or for process work. The obvious advantage of this arrangement is that the heat in the steam which would otherwise be rejected to the circulating water in the condenser, is used with the maximum efficiency in the process plant.

As an alternative to the use of extraction turbines it is possible to use back-pressure turbines in which the whole of the steam is exhausted at the lower boiler pressure.

Some public-utility power stations have adopted this device by installing new high-pressure boilers and a separate back-pressure turbine through which steam is passed into the lower-pressure steam main from which the old plant is supplied.

This method of raising the steam pressure above that required for the process work or low-pressure units, and obtaining additional power with a small extra consumption of fuel, is the modern version of what used to be done some 30 or 40 years ago by compounding single-expansion, horizontal, steam engines driving rolling mills. Many of these engines had a high-pressure cylinder fitted behind the low-pressure cylinder and the steam pressure was increased, although sometimes improved consumptions were attained with the same pressure.

Capacity of Turbines in Iron and Steel Works

As regards the plants which have been installed in iron and steel works power stations during the last few years, information is available regarding 81 of them. The detailed particulars of these 81 turbines, divided into groups according to size, are as follows :

Up to 1000 kW.	3
Over 1000 kW. and up to 1500 kW.	16
„ 1500 kW. „ „ „ 2000 kW.	17
„ 2000 kW. „ „ „ 2500 kW.	16
„ 2500 kW. „ „ „ 3000 kW.	3
„ 3000 kW. „ „ „ 5000 kW.	17
„ 5000 kW. „ „ „ 7500 kW.	4
„ 7500 kW. „ „ „ 10,000 kW.	–
„10,000 kW.	5

Only five units exceeded 10,000 kW. in capacity, whilst the average size was 3110 kW., and the median size, which represents more truly the size usually installed in these stations, was 2250 kW.

With the tendency to increase the size of individual units of production in all industries, is it not probable that iron and steel works will also increase their furnace capacity, and that they may be justified in installing larger blowers and turbines which in turn would enable better operating conditions to be utilized ?

If a combined iron and steel works with electrically driven mills were to provide sufficient generating plant for the larger motors, then the generating units would probably have to be very much larger than the present usual size, and in this case higher operating conditions might be satisfactory.

It is probably in the best interests of the iron and steel works that they should purchase power required for mill driving, from the electricity grid, as with the enormous capacity connected to the grid system, it is well able to stand up to heavy peak loads ; peaks which might seriously inconvenience a small power station.

There are many rolling mills which obtain their power from turbo-driven direct-current generators. On the turbine and generator shaft a heavy flywheel is mounted, and the peak load is met by the energy given up when the speed of the set is allowed to drop. By this means the turbo-generator unit is able to carry, for a short time, an overload up to 100% of the turbine capacity.

Condensers

The condensers usually supplied to iron and steel works are of the surface type, which have the advantage that they return the condensate to the system, with the exception of a small loss due to leakage. The condensers call for no special comment as they follow standard practice in all respects. In large power stations many of the turbines are designed with a double-flow final expansion with two exhausts on the low-pressure cylinder, and this usually requires the provision of two separate condenser shells connected by a suitable large-diameter balance pipe. In some cases these two shells are combined.

Many condensing plants now working in conjunction with a single-exhaust turbine have the cooling water circuit divided into two separate systems each supplying half the condenser. With this arrangement, or with the two separate shells, it is possible, by having suitably hinged doors at each end of the condenser, to open half the condenser and clean the tubes while the other half is maintaining a lower vacuum than when the full condenser surface is in operation. This arrangement, although provided on plants installed in the public-utility power stations, is not used to a great extent for the purpose for which it was designed, as experience shows that there are ample opportunities, under normal operating conditions, to clean the condensers as and when required.

In the works attached to iron and steel works where probably almost continuous operation is required from the generating plant, it might be advisable to consider the use of this type of condenser. Usually the iron and steel works power stations have not got the same stand-by plant that public-utility stations have by virtue of their connection to other stations through the electricity grid. It might, therefore, be worth while considering such condensing plants for the larger units in iron and steel works.

Most Economical Vacuum

As is well known, steam turbines are capable of utilizing high vacua efficiently from the thermal aspect, and there is, therefore, a tendency for engineers to specify a vacuum for a particular cooling-water temperature, which may perhaps be too high for maximum overall economy on a cash basis.

For public-utility stations the difference between the inlet temperature of the circulating water and the temperature corresponding to the designed vacuum should be about 21°–22° F., but instances have been known where quite experienced engineers have specified a vacuum for a given water temperature which only allows a difference of about 17°. Whilst this is quite possible technically, it does involve the provision of a very much larger condenser, and consequently a greatly increased capital cost, and increased running costs. The most economical value for this difference of temperature depends upon a large number of factors, including the variation in cost of the condensing plant and also of the turbine for the higher vacuum, the cost of coal, the total number of hours per annum during which the plant will be running, the average load factor during the running period, and other items. Taking reasonable values for these various items, it has been found that the following figures are approximately correct :

Running Time per annum, hr.	Load Factor during running hours, %	Economical Temperature Difference, ° F.
2000	20	24·45
8000	20	24·54
8000	60	23·18
8000	90	22·51

In an iron and steel works where sufficient gas is generally available, the value of the gas will be equivalent, for the purpose of this determination, to coal at a very low price, and Table I shows the approximate effect of a varying cost of fuel.

Plant in an iron and steel works will probably be running a very large number of hours per annum, and the lower figures in the last two columns are probably more applicable to such installations than the other figures.

TABLE I

Running Time, hr.	Load Factor, %	Economic Temperature Difference, ° F.		
		Cost of Coal per ton, shillings		
		10	20	40
2000	20	25·20	24·45	23·14
8000	20	25·06	24·54	23·65
8000	60	24·00	23·18	21·20
8000	90	23·90	22·51	20·33

If, in a particular iron and steel works, it is necessary to exercise the utmost economy in the use of waste gas, in lieu of which it would be necessary to purchase fuel, then doubtless a higher value would be attached to each unit of the gas. Under these circumstances it would probably be more economic to design the condensing plant for a smaller temperature difference than indicated above.

It would thus appear that, on the basis assumed in the above calculation, a temperature difference of some 22°–24° (according to the gas situation) is the minimum that can be justified. Depending, as it does, upon the actual variation of plant cost with vacua and the percentage of total cost debited against the plant for capital charges, it is not possible to go more closely into this section of the subject, but it would be difficult to justify a value of less than 20° for this temperature difference.

Feed-Water Discharge Temperature

For any given steam conditions at the inlet to the turbine, the heat consumption is reduced if the feed water is heated in heaters fed with steam extracted from the turbine. After a certain feed temperature, however, the heat consumption increases so that there is for each inlet pressure and temperature an optimum feed-water discharge temperature which gives the maximum efficiency. Increasing the feed-water discharge temperature involves more expensive plant, as not only is the heating plant larger and comprises more stages, but the turbine is also increased in cost to some extent. This is offset to some extent by a reduction in the amount of steam passing to the condenser (about 1% for each 18°–20° of temperature rise in the heaters) which is thereby reduced in size. The most economical feed-water discharge temperature, therefore, depends upon cost of the plant, the percentage of the cost debited for capital charges, the cost of fuel, the running hours per annum, and the plant load factor during those hours, etc.

It has been found that the most suitable temperature rise for each individual heater is from 50° to 60° F. With a vacuum of 29 in., the temperature of the condensate extracted from the condenser will be 79°, and this temperature will usually be increased about 6° due to the condensate being passed through the coolers of the steam-jet air extractor, so that its temperature at the inlet to the heaters will be 85° F. If it is to be raised to a final temperature of 300° F., giving a temperature increase in the heaters of 215°, there would usually be four extraction points and four heaters. Each point would be so selected that the saturated temperature of steam at a pressure equal to that at the tapping point, at the most efficient load or designed duty, would be 10° or 12° above the temperature to which the condensate is to be heated in the heater served by that tapping point. If this temperature difference is increased it may reduce the size of the heater, but would lower the overall economical performance of the plant to some extent.

Using reasonable values for these factors, the most economical feed-water discharge temperature with an initial steam pressure of 600 lb./sq. in. (gauge) and at 850° F., under different conditions of load and running time appears to be as follows :

Running Time per annum, hr.	Load Factor During Running Hours, %	Most Economical Feed-Water Discharge Temperature, ° F.
2000	20	296
8000	20	307
8000	60	324
8000	90	328

For the reasons mentioned in connection with the most economical vacuum, the figures given in Table II show the effect of variation in the value of fuel.

TABLE II

Running Time, hr.	Load Factor, %	Economic Discharge Temperature, ° F.		
		Cost of Coal per ton, shillings		
		10	20	40
2000	20	266	296	315
8000	20	283	307	321
8000	60	311	324	330
8000	90	318	328	333

This shows that with 600 lb./sq. in. steam pressure, a feed temperature of about 320° is probably the economic limit.

Figure 1 shows, diagrammatically, the arrangement of a two-cylinder turbine provided with four tapping points, the two higher-pressure tappings supplying high-pressure heaters on the discharge side of the feed pump. Sluice and non-return

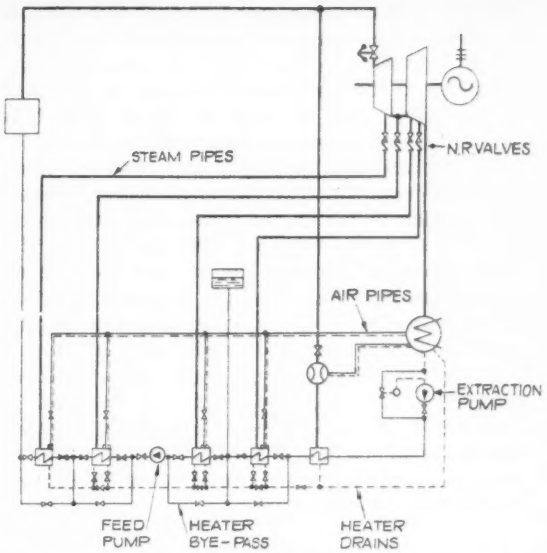


FIG. 1—Diagrammatic arrangement of feed heating plant using steam tapped from turbine

valves are fitted to each tapping point. Any air liberated in the heaters is vented back to the condenser, and the drains are cascaded to the next lower-pressure heater. Ultimately, these drains get back to the condenser.

Each heater is provided with an automatic by-pass, so that in the event of tube failure or other trouble it can be isolated. The extraction pump is provided with a control valve to maintain satisfactory operation at low loads. The air extractor supplied with high-pressure steam is also shown.

If the design of the boilers be such that it is not convenient or economical to use air heaters, then the above feed-water discharge temperatures may perhaps have to be reduced. In the large boilers used in central power stations, it is usual to incorporate air heaters in order to use the heat which otherwise would be used in the economizers to raise the temperature of the feed water. This question is tied up with the type of fuel or gas used to generate steam, and the method of using it. If chain-grate stokers be used, the feed temperatures would have to be reduced or the air temperature might be too high for the stokers. This point will be more adequately covered in the associated boiler paper.

Feed Water

When using steam pressures of 600 lb./sq. in. or upwards, it is essential that the feed water should have a high degree of purity and should be de-aerated. With surface condensers, the

condensate is well de-aerated, so that this portion of the feed water will be in a suitable condition. When, however, steam is used in process work, the whole of the condensate may not be returned to the plant, and in order to make good this deficiency, and also to replace condensate inevitably lost through leakage, evaporating plant should be installed. This can be operated between two tapping points on the turbo-alternator units. The evaporator is supplied with steam from the higher-pressure tapping point, and the vapour made is led into the heater which normally would take steam from the next lower-pressure tapping point. This arrangement will usually give a temperature difference of about 50°, which is reasonable for an evaporator. If the loss of condensate in the process work is very great, special arrangements may have to be made to provide the full quantity of suitable feed water for normal operation.

Cooling Towers

Presumably, in the majority of installations there will not be a sufficient supply of natural cooling water for circulating purposes, and it will be necessary to instal cooling towers. Whilst many years ago a cooling tower with a capacity over 250,000 gal./hr. was considered to be quite a large one, the circular, concrete, hyperbolic towers have a capacity up to five-million gallons per hour. They have a very good draught, and a bottom water temperature of 75° F. can be guaranteed with the average atmospheric conditions of 55° F. and 75% humidity, corresponding to 51° F. wet-bulb temperature. This bottom temperature depends mainly upon the wet-bulb temperature, although it is affected to some extent by the dry-bulb or atmospheric temperature.

Steam Usages in Iron and Steel Works

The steam is, or may be, required in an iron and steel works for the following purposes, grouped according to the probable suitable steam pressure :

Blast-furnace blowers Bessemer-furnace blowers Turbo-alternators Boiler feed pumps	High or medium pressure
Coke-oven gas exhausters	Medium or low pressure
By-product recovery plant Gas-cleaning plant Tar heating Oil heating Water-softening plant Space-heating	Low pressure

Blower Turbines

It has been indicated previously that, with higher steam pressures and temperatures the thermal efficiency of the plant is considerably increased, but that high pressures cannot be fully utilized in small units.

All steam turbines so far used in iron and steel works are too small to utilize steam at a pressure of say, 600 lb./sq. in. superheated to a total temperature of 825° F.

Provided, however, that there is no objection due to the varied needs of blast-furnace operation, it is possible to suggest a method by which efficient use could be made of steam at 600 lb./sq. in. and 825° F. Large turbo-blowers are now requiring an input of 5000 kW. up to 8000 kW. If these turbines be of the back-pressure type and be supplied with steam at 600 lb./sq. in. and 825°, exhausting at a pressure between 200 and 300 lb./sq. in. (gauge), then the situation is entirely changed. This type of back-pressure turbine could be regarded as the high-pressure end of a complete turbine which, from the inlet conditions of 600 lb. pressure at 825°, to a condenser maintaining a vacuum at the turbine exhaust flange of 28 in., would have a capacity of about 25,000 kW., as the full adiabatic heat drop from the inlet to the condenser is just four times that to 200 lb./sq. in. This equivalence is the justification for the use of the higher-pressure steam.

With a turbo-blower dealing with 80,000 cu. ft./min. and discharging at 15 lb./sq. in. (gauge), the turbine, exhausting at 200 lb./sq. in., would require about 160,000 lb. of steam per hour, the exhaust temperature being about 620° F. This exhaust steam could be used for driving the turbo-alternators which are required for supplying the power requirements of the works.

If such an arrangement be considered, it would probably be found better to drive the blowers by the back-pressure turbines rather than the alternators, as the latter will run consistently at one speed and do not require the speed variation which is necessary with a blower run according to the furnace requirements.

Power Turbines

The turbines driving the alternator could be of the straight condensing type, but as there is a very general requirement in all iron and steel works for steam at a lower pressure say, 100 lb./sq. in., they could be made of the extraction or pass-out type. Turbines of this type could exhaust any proportion of their total steam at a pressure of 100 lb./sq. in. (gauge), the balance passing to the condensers. Under these circumstances a 2000-kW. turbo-alternator, passing out 80% of the steam supplied, would take approximately

82,000 lb. of the steam at 195 lb./sq. in. and 620° F., or a 3000-kW. turbo-alternator, 120,000 lb. of steam per hour. The exhaust, therefore, from one back-pressure 80,000-cu. ft./in. turbo-blower would, under these conditions, be sufficient to generate approximately 4000 kW. of power, and at the same time these power turbines would pass out about 130,000 lb. of steam at a pressure of 100 lb./sq. in. Should this be more than is necessary to meet the low-pressure requirements of the works, the amount extracted could be reduced, and the amount passed to the condenser increased. This arrangement of back-pressure and pass-out turbine is shown diagrammatically in Fig. 2.

This diagram does not call for much comment, as the various components of the installation are represented graphically. Reducing valves are shown between the high-pressure steam main and the intermediate-pressure main (200 lb./sq. in.). The reducing valve is controlled by the pressure in the intermediate-pressure main, and would operate if the load on the back-pressure blower turbines were reduced considerably, and the existing intermediate-pressure boilers were unable to supply all the steam required by the power turbines. Similarly, another reducing valve is shown between the intermediate-pressure main and the low-pressure main, also controlled by the pressure in the latter. This diagram does not show the feed-heating connections which are shown separately in Fig. 1.

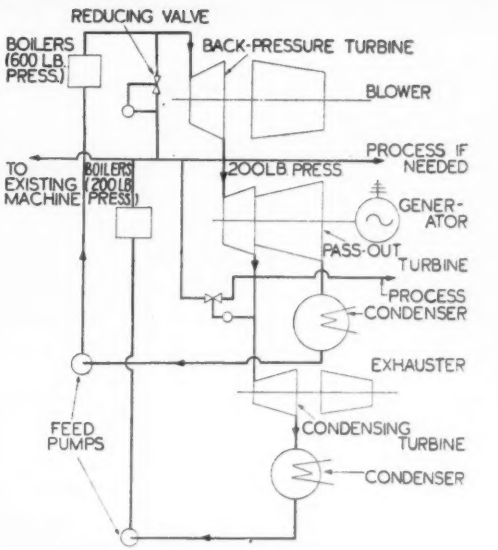


FIG. 2—Diagrammatic arrangement of blower, power and subsidiary turbines working in series

Geared Turbines

With a centrifugal blower, the rotational speed is reduced for larger outputs, due to the necessity of providing ample inlet area in the first stage. This implies a minimum inlet area around the hub of the first impeller, and therefore a minimum diameter for the impeller. With a fixed circumferential speed determined by the available materials, the speed of rotation must necessarily be reduced with large air capacities.

Although turbine builders are so heavily loaded at the present time, and apparently will be so for some time to come, that they are not anxious to be called upon to design special machines, it might be suggested that the high-pressure back-pressure turbine driving the blower could be of the geared high-speed type. The turbine speed might be 6000 r.p.m. or more, driving the blower at a suitable speed, which for 80,000 cu. ft./min. will probably not exceed 3000 r.p.m.

The use of high-pressure turbines running at higher speeds than low-pressure turbines is not unknown in power stations. This has often been done with cross-compound units driving either separate alternators or one alternator through gearing. It is standard practice with marine geared turbines, to gear different-speed turbines to the propeller shaft.

In a certain large British power station there is one unit with a total capacity of 100,000 kW. which consists of a 16,000-kW. turbo-alternator running at 3000 r.p.m. and supplied with steam at a pressure of 1250 lb./sq. in. superheated to 925° F. This exhausts into a 84,000-kW. unit running at 1500 r.p.m.

Steam Balance

According to the requirements of different works it may be desirable that the designed back-pressure on the blower turbines should vary from the 200 lb./sq. in. herein assumed. If more steam is required, then the back pressure on the blower turbine could be raised, thus increasing the quantity of steam required and also increasing, very considerably, the amount of power which could be generated from the turbines driving the alternators. The power output would be increased, partially due to the higher inlet pressure at the inlet to the power turbines, and also to the greater quantity of steam exhausted by the blower turbines. Similarly, if the suggested pressure of 100 lb./sq. in., at which the steam is extracted from the power turbines, does not meet the requirements of the works, then it could be varied to any desired figure. In other words, these pressures can be altered in any way to enable the best heat or steam balance to be obtained. The design of steam turbines is extremely flexible and they can be made to meet any requirements.

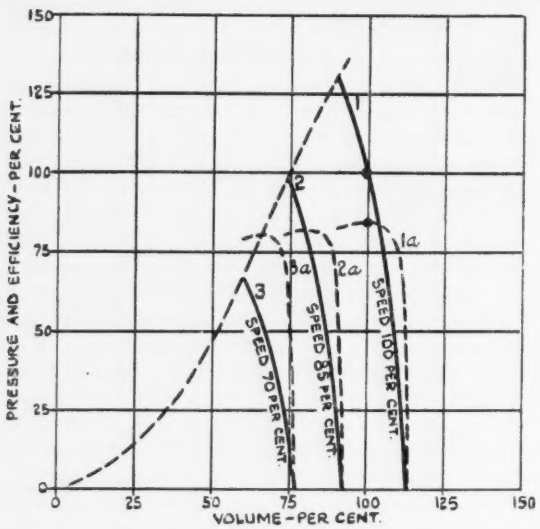


FIG. 3—Pressure/volume curves (1, 2, and 3) and efficiency curves (1*a*, 2*a*, and 3*a*) for axial blowers

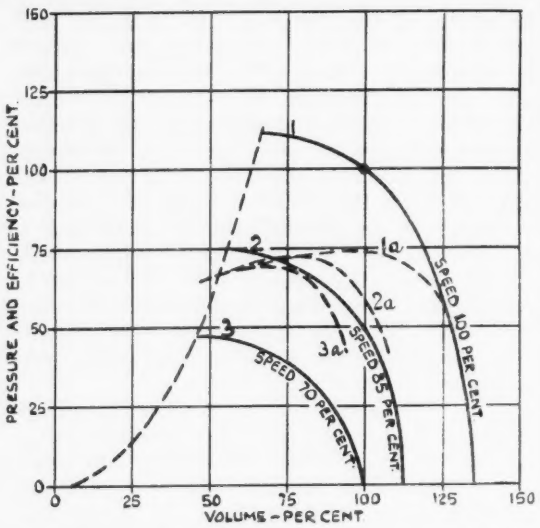


Fig. 4—Pressure/volume curves (1, 2, and 3) and efficiency curves (1*a*, 2*a*, and 3*a*) for centrifugal blowers

Type of Blower

So far, it has been assumed that the blowers must be of the centrifugal or radial-flow type, now universally used for blast supply. In connection with the development of the gas turbine, very considerable progress has been made with the design of axial-flow blowers or compressors, and they may be suitable for blast blowing.

Whether the blower be of one type or of the other is really of no importance to the engineer in charge of the blast-furnace. From his pressure gauge at the furnace, his knowledge of the volume of blast being handled, and the furnace burden, he can decide whether the pressure should be increased at constant volume or the volume be decreased at a constant pressure. Provided that this flexibility is available, either type can be used, and the choice will be determined by the other advantages of one type over the other.

The main difference between the two types of blowers is in their characteristics, *i.e.*, the curves showing the relations between pressure and volumes at various constant speeds. At a constant speed, the centrifugal characteristic is not as steep as that of the axial type. This is illustrated by Figs. 3 and 4. Thus at constant pressure, in order to reduce the volume, the speed of the centrifugal has to be reduced very much less than is needed with the axial blower. The pumping limit, below which surging occurs, is indicated by the dotted line rising to the right and passing approximately through the maximum pressure points on the characteristics. Owing to the steeper characteristic of the axial blower, the point representing the designed duty, *i.e.*, the specified volume and blast pressure, is much nearer to the surging limit than is the case with the centrifugal type. That is a drawback, but not insurmountable. With the centrifugal blower, movable diffuser blades can be fitted to a proportion of the stages, and the pumping limit can be taken back to as low as 20% of the designed volume. This remedy does not appear to be applicable to the axial machine ; an automatically controlled blow-off valve would be fitted between the blower discharge and the non-return valve in the blast main. Any reduction in flow to the furnace would, through a relay actuated by the pressure in a venturi tube throat, open the blow-off valve and increase the flow through the blower above the surging limit. Between the design duty and the surging limit a constant-pressure regulator would control the operation, but for lower volumes the blow-off valve would open.

At the designed duty, the axial blower, except for small sizes ; is more efficient than the centrifugal, but, if at constant speed the volume be either increased or decreased, the efficiency falls rapidly. Whether the blower be required to maintain either constant pressure or constant volume, the speed would vary, and for each speed there would be a fresh characteristic. If the control were so arranged that the running conditions at each speed correspond to the maximum efficiency point, then the fall in efficiency at constant speed for any departure from the design duty would be no drawback. This variation of efficiency with volume at any constant speed is indicated by the three similar dotted lines in Figs. 3 and 4. Below the surging limit the higher efficiency of the axial blower is neutralized by the waste through the blow-off valve. Only

the blast-furnace operators can say whether the loss is sufficient to rule out the axial blower.

The blast-furnace engineers cannot be quite sure, in advance, of the blast pressure and volume that will best suit a new furnace. If the new furnace is to be a repeat of an existing furnace and is to use the same ore and coke, the divergence between anticipated design duty and actual requirements need not be great. To cover possible variations in a new installation the furnace engineer will, doubtless, add a margin to his anticipated need. If this margin should prove to be unnecessary then it should be appreciated that the operating point on the pressure/volume line has been brought nearer to the surging limit by the amount of the margin.

Either type of blower can be provided with both constant-volume and constant-pressure automatic control. Either of these controls can be in charge of the blower, according to the furnace requirements.

There are, then, very many points to be considered before axial-flow blowers can be generally accepted for blast-furnace operation, and it would appear to be a case where both blast-furnace engineers and the manufacturers of turbines and blowers could be of considerable assistance to each other. If there were opportunities for representatives of both sides to get together and discuss the matter fully, it could only lead to some improvement in the situation, and might result in more efficient operation of the blowers and furnaces without an undue amount of complication. The blower designers may be inclined to include certain features which to them appear to be an improvement, but of which the value to the blast-furnace engineer is not as great as the designer anticipates. Such a round-table discussion could bring out these points and elucidate the problem to the advantage of both sides.

Summary

It may be desirable to crystallize the various suggestions made in this paper, as follows:

1. The advantages of using back-pressure turbines for driving blowers.

2. The turbines of the power units to work in series with the blower turbines.

3. The turbines of the power units to pass out steam at a pressure suitable for the subsidiary needs of the works.

4. Turbines of the power units to be provided with tapping points to heat feed water to a temperature of 260°–320° F.

5. The condensers to be of the cleaning type.

6. The economical vacuum to be determined in relation to the temperature of the available circulating water, the load factor, and other variables.

7. Feed water to be de-aerated and as free as possible from all scale-forming material.

8. Between two tapping points on the power turbines an evaporator should be installed to make up the loss of feed water.

9. The possibility of using geared turbines for driving large blowers.

10. The use of axial-flow blowers to be considered.

11. A round-table discussion between the engineers responsible for blast-furnace operation and those responsible for the design of the turbines and blowers should be considered.

Acknowledgments

The author wishes to acknowledge that Figs. 3 and 4 are reproduced by consent, from a paper entitled "The Combustion Gas Turbine, its History, Development and Prospects," by Dr. Adolph Meyer (*Proceedings of the Institute of Mechanical Engineers*, 1939, vol. 141, pp. 197–212).

The author wishes to thank the various turbine builders and others who have assisted him in the preparation of this paper.

Water-Tube Boilers for Iron and Steel Works*

Submitted by the Water-Tube Boilermaker's Association

THE earliest boilers used in ironworks were simply plain cylinders with hemispherical ends, termed 'egg-ended' boilers, perched on brick-built furnaces. Boilermakers of those days were handicapped by the small sizes of boiler plates available, for example, the egg-ended portion of a boiler 5 ft. in diameter was built up of 10–12 separate pieces. Boilers were charged by hand with any available coal, and as steam demands increased it was not uncommon to find boilers massed in groups of 12, 18, or even 24. The ground space occupied by such large groups of boilers was out of proportion to their value as producers of power.

In the 1850's the Lancashire boiler with the familiar pair of large tubular flues came into use, having also passes for the boiler gases in flues of external brickwork. Higher ratings were then possible, and working pressures gradually increased so that 100 lb./sq. in. was not considered too high. Shell boilers continued in satisfactory service in iron and steel works for working pressures up to 200 lb./sq. in. For supplying steam to engines driving plate or section rolls they have the valuable feature of large thermal storage. This feature enables them to function as semi-accumulators by giving off additional low-pressure steam when a sudden increase in load absorbs more than the normal output of steam.

A great impetus to the development of iron and steel works came with the invention of the Bessemer converter, when steam power had to be rapidly augmented to cope with the increased demand for steel. The water-tube boiler solved the twin problems of lesser floor space and higher working pressure, and could also deal more satisfactorily with the special fuels available such as blast-furnace gas and coke-oven gas. The higher working pressures possible with water-tube boilers were advantageous when electrical driving motors and other electrical equipment became available, as it enabled steelworks to instal their own generating plant.

The steam requirements of most ironworks and steelworks are, however, comparatively modest when compared with those of a central power station, and only in exceptional cases are the modern developments in very high steam pressures and temperatures applicable to steelworks practice. The steam pressure of water-tube boilers in steelworks ranges from 200 to 450 lb./sq. in., and evaporative capacities range from 20,000 lb./hr. up to 100,000 lb./hr. Some regard should, nevertheless, be paid to the increased efficiencies obtainable with larger turbine and boiler units operating in the higher pressure and temperature ranges. Higher working pressure involves higher capital cost of equipment, both for the turbine and the boiler plant, but the saving continuously effected under suitable operating conditions may soon outweigh the extra capital cost.

Recent events may, of course, affect the trend of development in this country as regards the alternative policies of individual production of power, or purchase of the bulk of supply from the Grid. So long as the tendency to take power more and more from the Grid persists, so will the majority of turbine and boiler plants in steelworks remain small and relatively inefficient, operating at low pressures and low steam temperatures. The capacity of the boiler plant and the steaming conditions will be governed by whether the steam is required for process (*e.g.*, by-product coke ovens), power, or heating. Often a more economical scheme can be obtained by making use of pass-out or back-pressure turbines, which allow the use of a higher initial pressure and temperature.

There are no difficulties likely to arise in the design of the boiler plant in connection with the required capacity, steam pressure, or temperature. For example, a certain motor-car manufacturing concern in this country who make their own steel and also generate their own power, has, for the past 15 years, been using three high-pressure boilers working at 1250 lb./sq. in., and each having a capacity of 205,000 lb./hr. evaporation when burning pulverized coal, although a somewhat lower capacity is accepted on gaseous fuels.

So far as concerns the boilermaker, the emphasis is rather on the complexity of the special requirements of the steel industry as regards provision for unsteady steam demand and the combustion of unusual types of fuel. Any difficulties that do arise are, therefore, more likely to be associated

* Paper prepared by R. F. Davis, A. L. Napier and A. S. Peacock. Received 3rd April, 1947.

with the firing of the boiler. Our attention will be focused first then, upon the question of fuel and the design of the combustion chamber.

Boiler Fuels and Furnaces

Gaseous fuels are more often used in ironworks than solid fuels, and of the former, blast-furnace gas is nearly always the first choice for steam raising. Depending on the degree of economical integration of the plant, coke-oven gas may also be employed, although in some cases where the plant is connected to a local gas Grid, it is more economical to export the coke-oven gas and make up the balance with solid fuel. In a steelworks there is also available a certain amount of inert waste-heat gas from open-hearth furnaces, which can be used for the generation of small quantities of low-pressure steam, but this does not, of course, require a combustion chamber and presents no problems to the boiler designer.

The ideal arrangement is where the volume of blast-furnace gas available for the boilers is sufficient to meet normal requirements, and fuel oil, creosote pitch, or pulverized fuel is used for peak demands or to meet at a moment's notice any deficiency in the gas supply. For small plants the comparatively low installation costs of oil-fuel equipment for emergency use is very attractive, but in larger plants the advantages of pulverized fuel merit careful consideration.

Boilers designed to operate with gaseous fuels are readily adaptable to oil fuel ; it is possible to obtain combination burners which will deal with either gas or oil, so that a rapid change-over can be made. Creosote pitch can also be utilized in the same way as oil fuel, providing suitable atomizing equipment is installed.

The blast-furnace gas supplied to a boiler should be cool, clean, and dry. It is perhaps more important that it should be cool and dry than clean, because providing the moisture content is low, the dust will not adhere to the boiler tubes and form hard deposits. A hot gas can contain more moisture as saturated vapour, and this results in a lower flame temperature in the furnace and reduces the rate of radiant-heat transmission to the boiler tubes. A certain amount of fine dust, on the other hand increases the emissivity of the flame, and with it the radiant-heat transmission rate.

Small boiler units utilizing blast-furnace gas are frequently of the horizontal straight-tube type with hollow, air-cooled, suspended-block, refractory furnace walls. The combustion air, in circulating through such walls, is raised to a temperature approaching 200° F. before entering the burners. However, for large boiler units, the vertical bent-tube or tri-drum type of boiler is more usual, and is often found in combination with varying degrees of water cooling in the combustion chamber. A water-cooled combustion chamber will almost invariably be installed where pulverized fuel is the secondary fuel.

Although, theoretically, the combustion of a correctly proportioned mixture of gas and air is almost instantaneous, experience has shown the desirability of providing an ample combustion-chamber volume for blast-furnace gas. It is also as well to locate the burners as far from the boiler convection tubes as possible, in order to allow the air and gas jets to mix thoroughly. Where pulverized fuel is used in addition, the coal burners are often located in the sides or rear of the furnace, and the gas burners are protected from the intense heat of the pulverized-fuel flame by a deep grid of brickwork.

In some instances blast-furnace gas, or coke-oven gas, has been introduced above a travelling-grate stoker, more especially perhaps where it has been desired to burn coke breeze or a mixture of coke and coal by the 'sandwich' method. With this system, duplex storage bunkers, fuel chutes, and hoppers on the stoker give facilities for varying the mixture of coal and coke to obtain the best operating conditions. The cost of a stoker-fired plant is less than that of a pulverized-fuel installation, and the former is more simple to operate. In certain cases, however, the attractiveness of simplicity is outweighed by the slower response to peak demands and readiness for emergency. When the boiler is operating on other than solid fuel and the stoker is not therefore in use, the grate surface must be protected by a layer of crushed refractory or, for more permanent periods of disuse, by solid tiles. When operating the stoker, care has to be exercised to ensure that the bed of fuel or ash is sufficient to prevent the grate from overheating.

Whether gaseous fuel is used in conjunction with a stoker or not, the combustion chamber is now generally designed as an 'archless setting,' in which the heat for distillation of the green fuel is obtained by direct radiation from the incandescent gases above the active zone. This kind of setting has been found satisfactory for coals ranging from semi-anthracites to bituminous. With fine anthracites, or coke breeze fired on its own, a long rear arch is, however, necessary, and the method of operation is to maintain the main combustion zone well to the rear under the arch. Completion of combustion of the gases above the grate is ensured by the introduction of high-pressure-air jets through the front and rear furnace walls. In large stoker-fired plants the combustion-chamber walls are either partially or completely water-cooled.

Pulverized Fuel

The change from the bunker, or central system of firing, to the unit system with drying in the mill circuit, has resulted in making pulverized fuel more readily adaptable to the smaller boiler unit. Various types of pulverizers are available, each having its own specific advantages for certain classes of coal or system of firing. The choice between having the mill under suction or pressure seems about equal; with the former system, maintenance of the fuel fan is an obvious disadvantage; with the latter, difficulty in obtaining complete pressure sealing is still often apparent.

Except in the case of very small boiler units, or where a low volatile fuel has to be burnt, it is recommended that water cooling of the furnace should be as complete as constructional requirements permit. Completeness of water cooling is no deterrent to effectiveness of combustion, provided there is no interference with ignition and propagation of the flame; this is equally true when firing gaseous fuels. The construction of the furnace cooling surface usually consists either of bare tubes, when closely pitched plain tubes or finned tubes are employed, or of tubes covered by either metal or refractory blocks; although where ignition and conditions of flame propagation permit, the latter construction is being superseded by the bare-tube type. The majority of furnaces now under construction also incorporate a fully cooled open-mouthed ash hopper in place of the former practice of having a widely pitched water screen across the bottom of the furnace.

Pulverized-fuel burners are generally of the type in which both the primary air, carrying the fuel in suspension, and the secondary air are introduced through concentrically placed nozzles; mixing in some cases being effected in the burner itself. Such burners are usually horizontally set, or tilted towards the furnace hopper, and are frequently opposed to each other, being set in opposite furnace walls. The long flame producing arch-mounted burner is now only used for the combustion of coals of low volatile content, such as anthracites and semi-anthracites.

For large water-cooled combustion chambers a specialized technique known as corner firing has been developed. The burners are set in multiple tiers in each corner of the furnace, coal being fed round from each mill unit to a burner nozzle in the same horizontal plane. The nozzles are set to fire tangentially to a circle at the furnace centre, with the result that an intense swirl is set up in the furnace at right-angles to the general direction of flow of the gases upwards to the furnace exit. Corner burners normally fire horizontally, but can be made adjustable to move through a total arc of about 50°. This feature provides a ready means of adjusting gas-temperature conditions both at the top and bottom of the furnace, and consequently can be used as a control of steam temperature and also to control slagging.

Boilers and Superheaters

Where the bulk of the steam output is required to provide power for mill driving, a fluctuating steam demand is unavoidable. In some cases, a sudden rise in consumption can cause surging in the boiler-water level and result in carry-over of water. Carry-over of this type, which may be called mechanical priming, causes low superheat, and also in severe cases may result in damage to the turbine. During the reverse stage of a fluctuation, while the boiler pressure is rising again, the reduced steam flow through the superheater will cause excessive superheat and overheating of the tubes. The severity of these effects can be mitigated, but not entirely eradicated, by an adequate size of steam-and-water drum, and by the addition of a dry drum with a properly designed system of internal steam separators or baffles. A flexible firing system, in conjunction with some kind of automatic control, is also an advantage; even so, when mill delays occur, it may not be possible to prevent a boiler from blowing-off. In such cases a low-pressure hot-water storage system or steam accumulator which can absorb large quantities of excess steam, may be an economical proposition.

For a given rate of steam flow, the degree of superheat given to the steam depends on the temperature and velocity of the products of combustion passing over the superheater tubes. With fuels of such widely different characteristics as coal and blast-furnace gas, both the volume and the temperature of their products of combustion show considerable variation (*see* Table I below). Although some compensation is afforded by the fact that the products of blast-furnace gas, while greater in volume, yet are lower in temperature than the products from the combustion of coal; nevertheless, a difference in the final steam temperature is unavoidable as between solid and gaseous fuel.

To obtain high superheats, however, say above 750° F., the choice of superheater location is rather restricted. For instance, with a completely water-cooled furnace only a screen of two to four widely pitched boiler tubes may be permissible between the furnace and the superheater, so as to ensure sufficient temperature head between the gas and the steam. In such cases, when changing, for example, completely from coal to blast-furnace-gas firing, the superheated-steam temperature may rise by more than 50° F., a condition calling for some means of temperature control. Generally, by-passing a fraction of the gases proves a clumsy

TABLE I—*Combustion Properties of Various Fuels*

Property	Fuel			
	Bituminous Coal	Fuel Oil	Coke-Oven Gas	Blast-Furnace Gas
Gross Calorific Value Range, B.Th.U./lb.	10,000–13,000	18,000–20,000		
Gross Calorific Value Range, B.Th.U./cu. ft. ...			500–600	88–120
Average Gross Calorific Value, B.Th.U./cu. ft. ...	...	...	590	97
Average Net Calorific Value, B.Th.U./cu. ft. ...	...	...	520	95
Average Gross Calorific Value, B.Th.U./lb.	11,500	18,500	17,200	1360
Average Net Calorific Value, B.Th.U./lb.	11,000	17,480	15,200	1340
Theoretical Air/Gas Ratio (by volume)	...	...	5	0·7
Theoretical Air/Fuel Ratio (by weight)	8·7	14·0	11·3	0·75
Theoretical Maximum Flame Temperature, ° F. ...	3250*	3700*	3800*	2600*
Weight of Products per Gross Million B.Th.U. Generated by Fuel, lb.	850*	810*	715*	1300*

* These figures are without excess air. In practice, variation in the amount of excess air will substantially increase the range of differences between the fuels

and inefficient method of controlling the steam temperature, and recourse to attemperating or de-superheating the steam is preferable, combined with automatic governing of the de-superheater by means of a thermostat at the superheater outlet ; uniform superheat temperature can then be expected with change in fuels and also with change in evaporation.

The spray type of attemperator has the simpler construction, but since it involves the introduction of water into the superheated steam, and its subsequent evaporation, it is essential to ensure not only good mixing of the water and the steam, but also that the water should have a high degree of purity. To avoid scale and salt deposits distilled water is therefore preferable.

In the non-contact or surface-type de-superheater a proportion of the steam is by-passed through a nest of tubes submerged in boiler water in a separate vessel. The cooled steam, after passing through the de-superheater, mixes with the remaining proportion of the original uncooled steam, so that regulation of the amount by-passed through the de-superheater determines the final temperature of the mixture. Where the final steam temperature is so high that alloy steels must be used in the last stages of the superheater, it is definitely an advantage to interpose attemperation at an earlier stage, thereby ensuring that the final steam temperature, and thus also the metal temperature, does not rise above the design figure. Where the control range required is extensive, it may prove economical to combine de-superheating with gas by-passing, the de-superheater being only used in this case for making fine adjustments to steam temperature.

Economizers and Air Preheaters

With the exception of small boilers working under natural-draft conditions, when a relatively high stack temperature is necessary to produce sufficient draft, it is highly desirable from the point of view of efficiency, to extract the utmost heat from the products of combustion before discharging them to the atmosphere. With the assistance of an economizer, or an air preheater—or more frequently by means of both in combination—boiler efficiencies of 82–86% on the gross calorific value of the fuel are readily obtainable, with either solid, liquid, or gaseous fuels. The economical efficiency for any particular plant depends on the characteristics of the fuel and its cost relative to the capital investment on the extra heat-reclaiming equipment. When changing from coal to blast-furnace-gas firing, there is always a drop of a few per cent in efficiency, due to the larger volume of the products of combustion with gaseous fuels, but since blast-furnace gas in a cheap by-product, this slight loss in efficiency is of no account.

With a stoker-fired boiler the scope for economic heat recovery by means of an air preheater is limited by consideration of the maximum air temperature permissible entering the chain grate or louvres. The maximum is usually considered to be 300° F. With pulverized-fuel firing a much higher air temperature is possible and, indeed, is often necessary for drying the coal in the pulverizing mills ; frequently air temperatures of 500°–600° F. are required. If any balance of heat remains in the gases from the boiler outlet, which is not absorbed by the air heater, an economizer must be used in addition. As the best combination and arrangement of the different types of heating surfaces depends on the boiler pressure, feed-water temperature, and other factors, the designer has to consider each case on its own merits.

For pressures not exceeding 450 lb./sq. in., gilled cast-iron sectional economizers are generally

acceptable, but for higher pressures steel tubes are employed, either plain, or more often covered by short-section cast-iron sleeves shrunk on. The extended gills on the sleeves are so arranged that straight-through gas passages are formed throughout the height of the economizer. One advantage of this construction is that the velocity of the gas through the unit is usually sufficient to carry all the dust out in suspension; in many cases soot blowers are not fitted. For very high pressures, steaming-type economizers, and economizers with welded joints are being increasingly installed.

One of the early difficulties experienced with air heaters when applied to the reduction of the temperature of the products of combustion to 300° F. and lower, was the condensation of moisture from the flue gas, due to the metal being cooled by the incoming air to below the dew point. The acid content of the gases raises their dew point above the normal saturation temperature for a neutral vapour, moreover, the presence of acid encourages the corrosion of the metal and bonding of deposits. Plate-type air heaters are often provided with renewable sections at the air inlet end to increase their useful life. The most effective cure devised for air-heater trouble of this kind, however, has been the introduction of partial hot-air recirculation. Providing the air-heater surface is maintained above the dew point of the flue gases, which is normally about 120° F., no trouble is experienced, except in certain anomalous cases where abnormally high dew points have been recorded. It is the practice with static plate-type heaters to raise the ingoing air temperature by recirculation, and, except in the abnormal cases already mentioned, this has been found to maintain the air-heater surface clean and uncorroded for long periods of operation. The slight increase in forced-draft fan power inherent in recirculation is more than offset by the advantages of increased availability and thermal efficiency.

Fans, and Dust Collection

For both forced and induced draft, it is the general practice to use centrifugal fans with backward-curved blades. The blades of induced-draft fans are radially tipped if used with dust-laden gases, so as to be self-cleaning. Owing to the difference in the volume and pressure of the air required for the combustion of solid as compared with gaseous fuels, it is often convenient to instal two forced-draft fans where these alternatives have to be provided for, especially when automatic control is installed.

A wide choice of type of fan drive is available from among the following:

(*a*) Single-speed or two-speed squirrel-cage motor with damper, vane, hydraulic coupling or electromagnetic coupling.

(*b*) Variable-speed commutator motor.

The vane control system, using a single-speed squirrel-cage motor has the simplicity of damper control, and has for this reason proved to be very popular.

The problem of dust emission is not so acute in a steelworks, where the surrounding atmosphere is usually already contaminated, consequently the expense of electrostatic precipitation from the flue gases is not often contemplated. The coarse grits can, however, be very cheaply eliminated by utilizing the induced-draft-fan inlet scroll as the primary collector which, together with a small secondary unit, makes a very efficient apparatus for a stoker-fired boiler. Where a higher efficiency of collection is required, independent cyclone collectors will give 90–95% efficiency. When burning only liquid fuel, or clean combustible gas, a grit arrestor would obviously be redundant.

Automatic Control

An adequate discussion of automatic control for boilers would require a separate paper, and only passing reference to this absorbing topic can be made here. The basic intention of automatic control is the safe and efficient operation of the plant, and not the entire elimination of human interest in its operation; a state of affairs which can be induced by making a system too completely automatic. However, for boilers which are fired with widely different types of fuel, some degree of automatic control is essential.

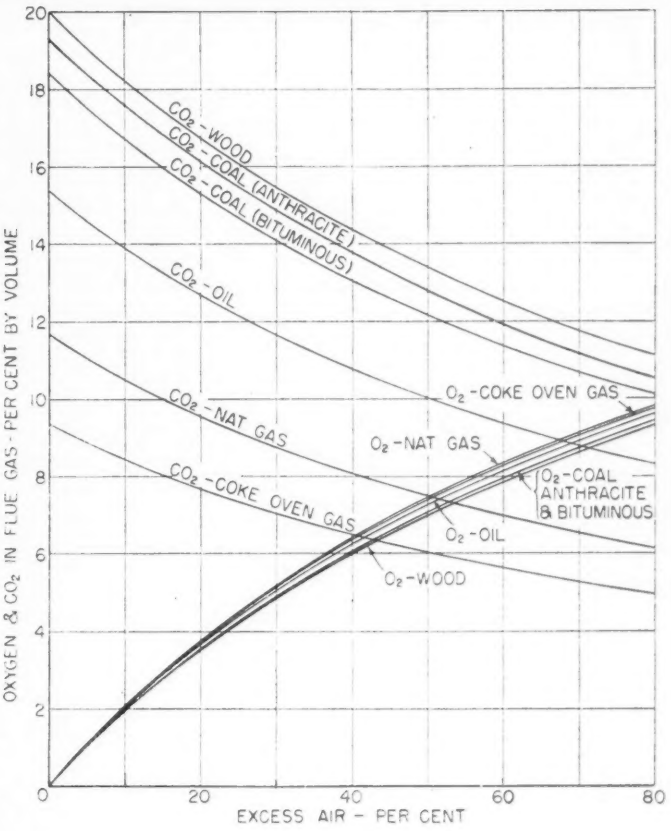
Automatic control of the feed-water supply has long been accepted as indispensable, but where the steam demand fluctuates, as it often does in a steelworks, a more sensitive control than the single thermostat working off the drum water level is desirable. Two-point or three-point controls are now procurable working in addition on the steam flow, and in the case of three-point, on the water flow also, as control media. Such devices can to some extent anticipate feed-water requirements, whilst the drum level mechanism only intervenes to apply a trimming influence, whereas if used alone, violent surges of alternate under- and over-feeding might occur.

Where one of the fuels is blast-furnace gas or coke-oven gas, the measurement of CO_2 is not an accurate indication of the combustion conditions, but instruments are available for recording the oxygen in the flue gas, which is a better guide (*see* Fig. 1). Even so, it is usual to fit automatic controllers for the air/gas ratio with a gaseous fuel. The usual system is to meter both the air and the gas flow by means of circular orifice plates located in the ducting—provided a sufficient length of straight duct can be arranged—and

the proportional flow of air to gas is maintained by a ratio controller. Alternatively, the gas and air nozzles in the burners can be used as metering elements. It is also useful to be able to regulate automatically the auxiliary fuel supply, to provide a steady steam output. In this case it is an advantage to be able to operate separately one forced-draft fan with solid-fuel firing and another with gas firing.

For maximum efficiency, adjustments to the boiler plant, however small, must be made immediately and accurately, and it is here that variable results are obtained when carried out manually. Various control systems have been developed. The motive powers in common use for actuating controlling mechanism are compressed air, electricity, and oil; naturally the designs developed by the various manufacturers differ widely. The fundamental purposes of each system are, however, the same, and may be set down as having the following objectives:

1. The maintenance of a constant steam pressure at a selected point in the steam range.
2. The maintenance of a constant suction in the furnace.
3. The maintenance of combustion conditions at the optimum value.



All systems of automatic boiler control incorporate means of remote manual control from the boiler panel, thus enabling the boiler to be manually operated whilst it is being brought up to range pressure without imposing any physical strain on the operator. The application of automatic combustion control relieves the operator from the necessity of making routine adjustments to the fuel and air supply, leaving him free to make a continuous examination of the plant under his care. It is conceivable that the mechanical nature of the control gear will detect small load changes that would normally escape the attention of manual operation and will mechanically apply suitable corrective action.

Availability and Cleaning

The dust content of blast-furnace gas may vary between only 0·01 grains and 5·0 grains per cubic foot, yet deposits will form on the boiler heating surfaces unless adequate provision is made for mechanical soot-blowing. The methods used in the works for cleaning the blast-furnace gas will have an effect upon the quantity and type of deposit, and it has been ascertained that, in plants using wet washing followed by cleaning in a precipitator to 0·6 grains per cubic foot, tenacious deposits have been formed on the boiler tubes; the latter are more difficult to remove than deposits from comparatively dirty gas from dry cleaning plants, with a dust burden approximating 2·5 grains per cubic foot. It has also been found that plants operating with a combination of gas and pulverized-fuel firing have generally resulted in cleaner heating surfaces, due to the scrubbing action of the pulverized fuel ash.

Modern soot-blowers, operated regularly, can and do give very long periods of availability, but the method of application of the cleaning equipment is at least as important as the design of the individual cleaning devices. In modern boiler design, the arrangement of the boiler heating surface may even be specially considered to suit the cleaning equipment known to be necessary. Since the appearance of remote-controlled power-operated blowers, automatically controlled sequential blower systems have been developed for large boilers, operated from the boiler control panel.

Water lancing has also been used to some extent for the removal of hard bonded deposits, as

complementary rather than as a substitute for soot blowing. Lancing is carried out whilst the boiler is on load, as it depends for its success on the sudden chilling of the bonded deposit and the consequent creation of thermal stress. Limited water washing of economizers is also possible during stand-by conditions ; again, certain types of air heater, when suitably equipped with by-passes and drain chambers, may also be water washed whilst on load.

Water Treatment and Steam Purity

The subject of boiler feed-water treatment is the province of the specialist and only general broad outlines can be indicated here. Unlike central power stations, the location of a steelworks is not chosen with reference to available water supply and frequently, therefore, 100% make-up may have to be legislated for ; but modern feed-water-treatment plant is able to cope with this situation and also the more exacting requirements imposed by higher boiler pressures. The extra cost of feed-water treatment and boiler-water conditioning must, however, be given due consideration and weighed against the advantages of higher operating pressure.

Preliminary softening is usually required to eliminate calcium and magnesium salts, by either a lime–soda process or by a base-exchange process. A recent development is the use of organolites, or organic base-exchange materials,in a demineralization plant, from which the water emerges with a solids content of less than 10 parts per million. In either case a de-gasification process is still necessary to reduce the oxygen content to less than 0·02 c.c./l. Subsequent oxygen ingress can be safeguarded by the continual addition of caustic soda and sodium sulphite. After treatment, conditioning or the injection of sodium phosphate into the boiler system causes the residual hardness to be precipitated as a soft easy-flowing sludge which can be removed by blowing-down.

The concentration of dissolved salts permissible in the boiler water depends on their nature and the operating pressure. Control is achieved by frequency of blow-down which, with a 100% make-up, will almost certainly require to be continuous, otherwise there may be risk of priming by foaming, which is not easy to correct by the usual boiler-drum internal baffles and steam separators. The quality of the steam is measured by condensing a sample and measuring its electrical conductivity. Continuously recording conductivity meters are now available, so that the boiler operator may be warned immediately the steam purity is dangerously threatened. The carry-over of salts in the steam may result in salt deposits building up in the superheater tubes and on the turbine blades.

Coal and Ash Handling Plant

The installation of coal and ash handling plant entails a fairly heavy capital expenditure, and where the firing arrangements are such that solid fuel is only used occasionally, this expenditure may be difficult to reconcile with the comparatively small total amount of solid fuel handled during any one year. It follows that the simplest possible plant layout is desirable. A typical arrangement of a large coal-handling plant would involve the introduction of a wagon tippler adjacent to the boiler house, with either gravity bucket conveyors, or inclined belt conveyors to elevate the coal to the boiler-house bunkers.

In the event of coal storage capacity being required, it would necessitate some means of distributing the coal from the wagon discharge point to the store, together with adequate means for reclaiming. The latter operation can be performed by bulldozers or mobile loaders if only small quantities are involved, or, if on a larger scale, preferably by drag-scraper conveyors. In some cases the site conditions may be such as to favour the transportation of coal to and from the store—and possibly also from the unloading point —by means of a telpher track running over the top of the boiler-house bunkers.

The size of the ash-handling equipment is normally determined by the maximum quantity of coal that is likely to be burned, but if it is only under emergency conditions that the quantity of ash is substantial, there are two alternatives to be considered ; either the installation of (*a*) a simple ash plant which would be worked at high ratings for only short periods, or (*b*) an expensive plant which for long periods would not be working to capacity.

With stoker firing the ash is collected in hoppers, and the simplest arrangement is the introduction of water sprays in the hoppers to cool the ash, with water collecting gates on the outlets ; the ash being discharged into hand-propelled wagons, for disposal. More elaborate systems provide for continuous discharge of the ash ; one method being by paddle ash extractors, which are water-immersed and continuously discharge the ash either into skips, or alternatively, on to a belt conveyor. With any of the above systems a skip hoist and an ash-storage bunker can be incorporated. A further means of continuous discharge is the submerged belt conveyor, which forms an air seal on each stoker hopper and conveys the ash direct either to a skip hoist or to a storage bunker.

With pulverized-fuel firing the ashing system can be again of a simple type, incorporating water sprays in the ash hopper and discharging into ash wagons, provided only small quantities have to

be dealt with. Where the quantity exceeds 10 tons per hour, the intermittent sluiceway ashing system is preferable. The disposal of the large quantities of dust associated with pulverized-fuel plant is, however, more likely to be a problem than that of the material from the ash hoppers. Pneumatic systems are available to create the necessary suction to discharge the dust to receivers, but these introduce exhausters requiring fairly substantial power units. The ultimate method selected for handling the dust depends largely on site conditions and the location of the dumping site. Removal of the dust in the dry state by wagons is only suitable for small quantities, and generally a hydraulic system is cleaner, and moreover essential, if large quantities have to be handled.

Conclusions

An attempt has been made to cover in a general descriptive manner modern water-tube boiler-plant practice with special emphasis on its application to the present conditions existing within the iron and steel industry. The complexity of the steam and power requirements of a steelworks plant is fully appreciated, and it is realized that often steelworks engineers have not been able to design their power plant to the best advantage. At the outset the steelworks engineer has to decide from technical and economical considerations the uses to which sources of heat made available by the production of steel shall be put. For example, whether coke-oven gas shall be sold, or burnt under boilers.

He has also to decide whether the works shall be self-sufficient in electricity supply, or whether any deficiency shall be made good by bulk purchase from the Grid. If a decision is taken that the works shall be self-sufficient, then obviously the size of the turbo-alternator set will be larger than if electric power is imported. In this case, steam pressure and temperature conditions corresponding to those which have been current practice in central power stations for a considerable number of years would probably be justified, both technically and economically, especially if back-pressure sets were installed ; the high-pressure steam being used to operate the turbine blowers, and the exhaust steam being taken to low-pressure turbines coupled to alternators supplying the general electricity demand of the works. Conversely, if the electricity demand is relatively small, then for technical reasons a somewhat lower steam pressure would be preferable. Whichever steam cycle is selected, the boilermaker will be able to meet the requirements.

Almost all schemes for boiler plant for steelworks involve the burning of one or more gaseous fuels. Such boiler plant would be simpler and lower in capital cost if no other fuels had to be dealt with in addition. It is, however, seldom that such favourable conditions are put before the boiler designer. The fuel which can most readily be handled as supplementary to gas, and at lowest additional capital cost is liquid fuel. Liquid-fuel handling equipment is very much lower in cost as compared with the equipment which is required to handle solid fuel, and in addition, no ash-disposal problem presents itself. If, however, it is necessary to burn liquid fuel in large quantities, it may be ruled out on grounds of uneconomic running costs ; in which case solid fuels come into question. These may be coal of any of the many varieties available in this country, or metallurgical coke. If the preference falls on coke, then this means that it is almost inevitable that stoker firing shall be adopted ; the abrasive nature of coke makes it unsuitable for pulverizing. Again, if coal is selected, then pulverized-fuel-fired boilers come into the question equally with stoker-fired boilers. For moderate-sized units, stoker firing is usually found to be somewhat lower in initial cost than pulverized-fuel firing, particularly if, due to the location of the works, pulverized fuel would call for elaborate grit-arresting equipment. On the other hand, as has already been mentioned, a load which is liable to fluctuate suddenly and between wide limits, can be followed better with pulverized fuel than with stokers.

It will be seen that, while on the side of the steelworks engineer a very wide range of technical and economic problems present themselves when considering large extensions to plant, so also is a wide choice of boiler plant available to the boiler designer. It will clearly be in the interests of both sides, when preliminary plans are being evolved, that the requirements of each should be exchanged at the earliest possible date.

In conclusion, the authors would like to put on record the fact that the achievement of higher boiler operating pressures and temperatures—and many large central power-station plants will shortly be going into operation in this country with steam pressures above 1000 lb./sq. in., and steam temperatures of over 900° F.—has only been made possible by developments in the manufacture of alloy steels and boiler-drum forging processes carried out by steelmakers. Future progress towards still higher and more efficient steam operating pressures and temperatures depends on continued advance in the economical production of suitable alloy steels and the development of satisfactory processes of fabrication.

Gas Turbine Applications in Iron and Steel Works*

By A. T. Bowden, W. H. Gibson, J. W. Railly, and R. G. Voysey

Part I—Power Applications

By A. T. Bowden, B.Sc.(Eng.), Ph.D. (Edin.), M.I.Mech.E.†

Gas turbine developments have now reached the stage where this type of prime mover demands the most serious consideration in questions relating to the replacement of old, or the installation of new plant in iron and steel works.

War-time developments in aircraft propulsion have served to cloud the very considerable interest in (and development of) the industrial gas turbine *before* the war. By 1939, most of the established steam-turbine manufacturers in England and abroad were convinced that the advances which had been made in the design of axial-flow compressors as the result of applied aerodynamical research, combined with the mechanical and heat-resisting properties of the ferrous alloys even then available, made possible the construction of a reasonably reliable and economical industrial type of gas turbine. War-time developments in non-ferrous heat-resisting materials and high-heat-release combustion chambers have done much to accelerate what would otherwise have been a more leisurely but steady progress. By 1945, when British engineers were able to lay down the tools of war and devote themselves once more to peaceful pursuits, considerable experience was available of gas-turbine units designed for the most part by Swiss engineers and used in connection with Houdry oil-cracking plants in the U.S.A.

These particular gas-turbine units operated at temperatures not exceeding 550° C., and the heat-resisting steels used were ferrous alloys. In addition, a large volume of experience had been obtained in the operation of axial-flow compressors as used in Velox boiler plants. Gas-driven superchargers had also provided their valuable quota of operating experience.

So with these and other developments to draw upon, with the now well-known Nimonic and other types of heat-resisting materials available, and with a desire to make good the years given over to war-time production, it is not surprising that British engineers, in spite of heavy home and export commitments, have in a short time carried developments to the point where they are prepared to offer industrial gas-turbine units as alternatives to the better-known types of prime mover where fuel, site, space, and other conditions are favourable to the efficient operation of the former and not so favourable to the latter.

In the present paper, discussion of gas-turbine applications to iron and steel works is confined to units working on the 'open' cycle. In this (as distinct from the 'closed' cycle in which air, heated by external means, is circulated), the working medium consists of products of combustion which must be acceptable to the turbine and, where it is fitted, the heat exchanger. This sets limits to the types of fuel which may be burned in the open cycle, but otherwise its comparative simplicity has everything to recommend it for the relatively modest outputs demanded by iron-and-steel-works' power and blowing requirements. Blast-furnace or coke-oven gas, or a mixture of these gases, are ideally suited to the open cycle. Distillates, and certain types of part residuals such as 'pool fuel' have, in our own and others' experience, been satisfactorily burned, but experience, either here or abroad, with high-ash residuals such as boiler oil of 'Bunker C' type is, we consider, far too limited to allow our saying with certainty, at the moment, that such fuels are suitable for the open cycle.

Again, although much research and experiment have been and are being devoted to the burning of pulverized coal in the open-cycle gas turbine, and although some success has already attended the work, we are still a long way from the goal. We are unable to say whether such fuels can be used

* Received 28th March, 1947.

† Chief Research Engineer, Messrs. C. A. Parsons & Co., Ltd.

reliably in the closed cycle of operations, since experience with such is limited to an experimental plant in Switzerland, and none have as yet been made or operated in this country.

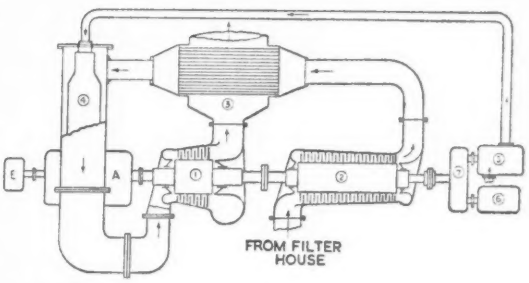
In view of the above considerations, and since it is not our purpose in this paper to deal speculatively with gas-turbine applications but rather to treat the subject conservatively, we limit the field in so far as iron-and-steel-works applications are concerned, to the open cycle and to the use of blast-furnace gas, coke-oven gas, heavy diesel or gas oil, and selected part-residuals of the ' pool fuel ' type.

A diagrammatic layout of an open-cycle gas-turbine power plant burning blast-furnace gas is shown in Fig. 1, and a suitable layout of such a unit designed for an output of 5000 kW. is shown in Fig. 2. Apart from low-efficiency units designed specifically for stand-by duty only, this represents the gas turbine in its simplest and cheapest form compatible with a reasonable working efficiency, the actual value of which depends of course upon the maximum temperature, the thermal ratio of the heat exchanger, and the component efficiencies.

As will be noted, the plant consists essentially of a single-line unit with the turbine coupled through a flexible coupling to the axial-flow compressor, alternator and starting motor, and through a step-up gear to the gas compressor. Part of the heat in the turbine exhaust is exchanged with the combustion air in the heat exchanger. The blast-furnace gas may, or may not be pre-heated by being passed through part of the heat exchanger.

The turbine and axial compressor call for little comment, except perhaps to mention that the blades for both, and the spindle and cylinder for the former are, on account of the high efficiencies demanded and the high temperatures obtaining in the cycle, rather costly items to produce. We prefer to use a centrifugal gas compressor since, although lower in efficiency than its axial counterpart, it is less sensitive to the effects of any impurities which may be carried over in the gas, and its characteristics allow more flexible control under varying load conditions. The heat exchanger for the operating temperatures likely to obtain for some time is, we consider, best designed as a simple, albeit bulky and heavy component, of normal shell-and-tube construction, allowing easy periodical cleaning. It is constructed of mild steel or carbon-molybdenum steel, and need not occupy valuable ' house room ' since with adequate insulation it may conveniently be installed outside the main building. With orthodox construction, practical upper values of heat-exchanger thermal ratios are of the order of 75–80%. Ratios largely in excess of these figures become prohibitive on account of the bulk and weight involved.

The combustion chamber is of the all steel type embracing the well-known double shell construction. The tertiary or diluent air which is mixed with the products of combustion, passes between the two shells and serves to keep both cool. A



A = Alternator
1 = Gas turbine
2 = Axial-flow compressor
3 = Heat exchanger
4 = Combustion chamber
E = Exciter
5 = B.F. gas compressor
6 = Starting motor
7 = Gear box

FIG. 1—Diagrammatic arrangement of gas-turbine power unit

flame-trap to prevent blow-back is fitted between the mixing chamber and the gas-and-air inlet lines.

The gas should be supplied from a gas-holder and should be cleaned. The degree of purity required is not yet certain, but Sidler* states a concentration not exceeding 0·013 grains/cu. ft. as being desirable. With normal wet or dry cleaning as at present practised, a dust concentration not exceeding 0·005 grains/cu. ft. is readily obtainable and, in general, the concentration will be less than this figure. The air for combustion must be filtered. In operating our gas turbine at Heaton, a filter of the ' Viscous ' type has given satisfactory performance. A starting motor is an inconvenient but necessary adjunct to the gas turbine. Normally, the gas turbine will become self-supporting at about 25% of its normal operating speed, and the starting power required is of the order of 5% of the normal net output of the unit.

The compression ratio adopted is determined by the maximum operating temperature, the heat-exchanger thermal ratio, and the pressure losses inherent in the system. In general terms it will be of the order of 4 : 1 for the simpler types of power plant, less for blowing plants, and more for larger two-line power plants.

* P. R. SIDLER : *Iron and Steel Engineer*, 1945, vol. 22, p. 35.

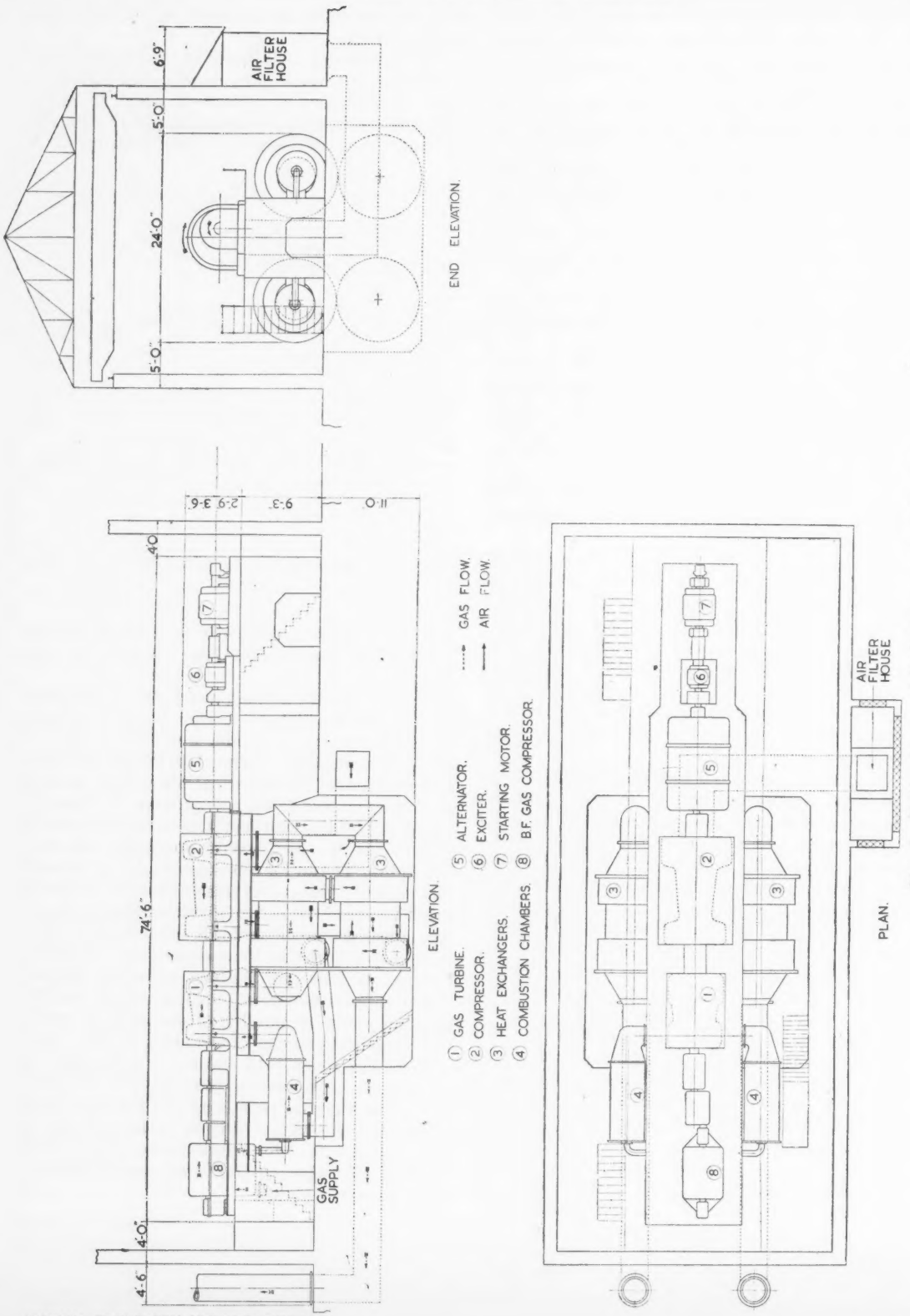


FIG. 2—Station layout of 5000 kW. gas turbo-alternator

Unless special methods of cooling the turbine rotor and blading are adopted, the upper temperature for a commercial unit, in the light of present knowledge of heat-resisting materials, would appear to be of the order of 1200° F. To provide a temperature margin against possible deterioriation of component efficiencies in service, this means a normal maximum operating temperature of some 1175° F. With average quality blast-furnace gas (1200 B.Th.U./lb.) the air/fuel ratio is of the order of 8–9 to 1. Taking high but reasonably attainable values for compressor and turbine efficiencies, and with gas and air at 70° F. and 14·7 lb./sq. in. we may, for the plant outlined, anticipate an overall efficiency of the order of 21–22%. This simple type of gas-turbine plant is, but for oil-cooling requirements, entirely independent of cooling water, and therein lies one of its chief claims to consideration.

It is, however, limited to units not exceeding some 5000 kW., and for larger outputs recourse must be made to a double-flow turbine and/or stage compression with interstage cooling. The effect of interstage cooling on reduction of the mass-flow for a given output is most marked, as may readily be seen from Fig. 3 which relates to an oil-fired unit fitted with a 75% heat exchanger.

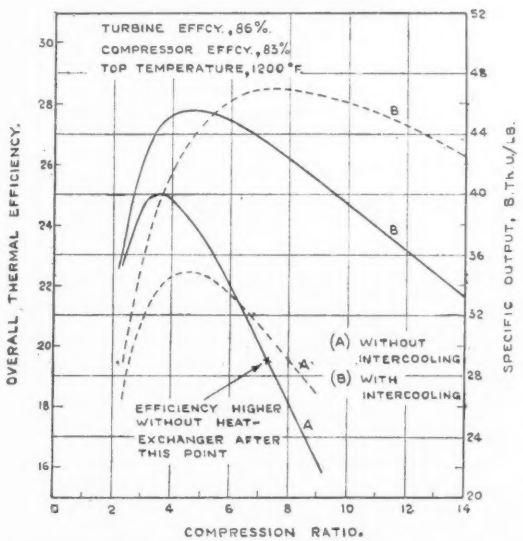
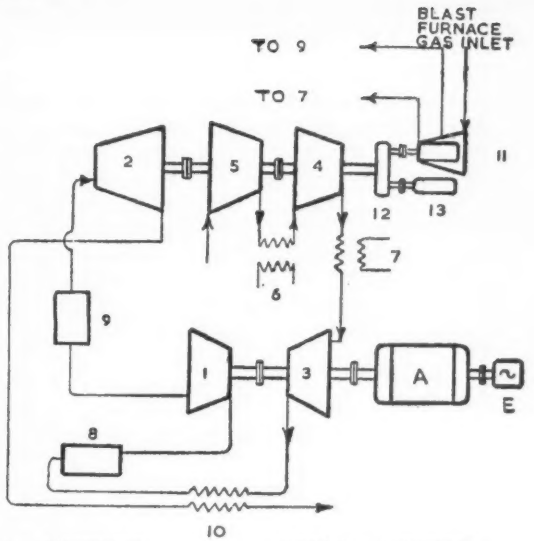


Fig. 3—Effect of one stage of intercooling on overall efficiency (full lines) and specific output (broken lines) of a simple cycle employing a 75%-effective heat exchanger

There is too, as will be noted, a not inconsiderable gain in overall efficiency, and so even for units of less than 5000 kW. output it will generally pay dividends to use stage compression and interstage cooling wherever water supplies are available.



A = Alternator
E = Exciter
1 = High-pressure turbine
2 = Low-pressure turbine
3 = High-pressure compressor
4 = Intermediate compressor
5 = Low-pressure compressor
6 and 7 = Interstage coolers
8 = Combustion chamber
9 = Heat exchanger
10 = Heat exchanger
11 = B.F. gas compressor
12 = Gearing
13 = Starting motor

Fig. 4—Two-line gas-turbine power unit

Using orthodox cross-flow coolers with a 10° temperature rise, the cooling-water requirements (for an inlet water temperature of 65° F.) for one stage of intercooling is of the order of 20,000 gal./hr. per 1000 kW. output, but with a counter-cross-flow type of intercooler the requirements may be cut down to some 25% of this figure. A layout for a 5000-kW. single-line unit with two-stage air compression and one stage of intercooling is shown in Fig. 5. A unit of this description, with temperature and other conditions as for the previous case considered, should have an overall efficiency of the order of 23–24%. The overall weight of a power unit of the type described is likely to be of the order of 200 tons including all auxiliaries and heat exchangers.

The majority of power units installed in iron and steel works in recent years have been of less than 5000 kW. output, and therefore the types of gas-turbine power units considered would meet most requirements.

For larger units of, say 10,000 kW. output, a two-line machine becomes advisable. The actual arrangement to be adopted depends on a large number of factors, including the load factor, importance of full- and partial-load efficiencies, fuel costs, and availability of cooling water.

Fig. 2—Station layout of 5000 kW. gas turbo-alternator

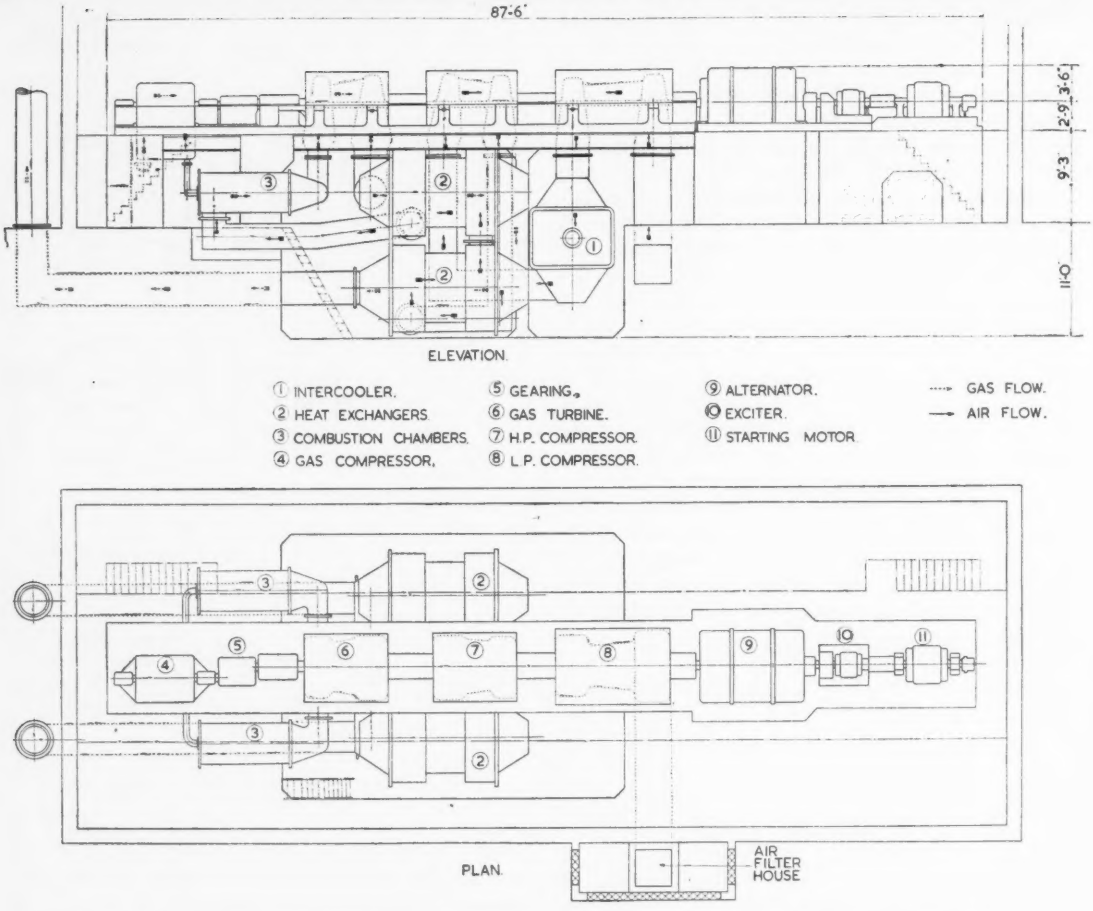


FIG. 5—Station layout of 5000 kW. gas turbo-alternator with 2-stage compression and intercooler

The highest efficiency will, in general, be obtained by using three-stage compression with two stages of intercooling and one stage of reheat. Theoretically, the compressor load should be carried quite independently of the work, thus allowing the compressors to run at their optimum efficiency irrespective of the alternator output, but it is generally more economical in first cost, and the part-load efficiency is not unduly affected if one stage of compression is tied to the constant-speed alternator line.

Such an arrangement is set out diagrammatically in Fig. 4. The feature not covered so far in our discussion is the reheating between the high-pressure and low-pressure turbines. This considerably increases the specific output, increases the efficiency, and increases the flexibility of the unit, in that it allows the whole or major part of the compressor group to be run at a speed independent of that of the work turbine. For part-load conditions this allows the compressor to run more efficiently than would otherwise be possible. The effect of reheat on specific output and efficiency is illustrated in Fig. 6 which relates to an oil-fired unit fitted with a 75%-thermal-ratio heat exchanger.

A two-line unit of the type shown should have an overall efficiency of the order of 26%.

Load control in the smaller and simpler single-line units is effected by throttling the gas supply from the gas compressor by means of a speed governor operating through an oil relay. In other words, load variation is effected almost solely by change in temperature (the mass flow remaining sensibly constant). This involves some sacrifice in part-load efficiency. Taking, for example, the 5000-kW. uncooled compression unit considered above, the overall efficiency at 50% load would probably be of the order of 15–16%. For a two-line unit it is possible, by control of fuel to both combustion and reheat chambers, to vary the mass flow (by slowing-down or speeding-up the

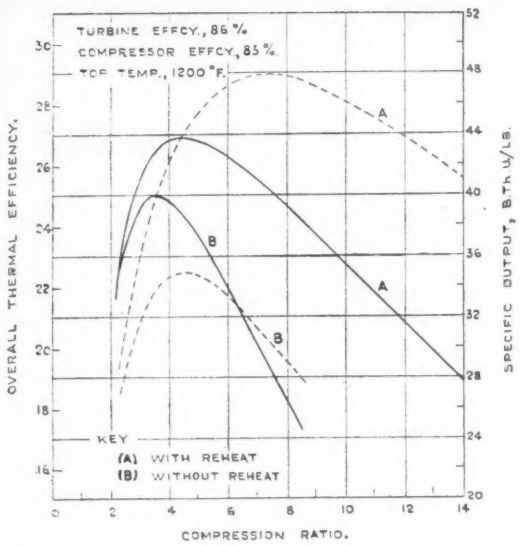


FIG. 6—Effect of reheat on the overall thermal efficiency (full lines) and specific output (broken lines) of a simple cycle employing a 75%-effective heat exchanger

compressor turbine) as well as the operating temperature of the work turbine. With this dual control the part-load efficiency is considerably better than is obtainable with a single-line unit. The 50%-load efficiency, for example, of the two-line unit of Fig. 4, would be of the order of 22%.

In all cases an over-riding temperature control is fitted to ensure that the designed operating temperature is not exceeded for any length of time. In all cases, the normal overspeed trip gear is fitted also. If necessary, for delicacy of response to load change, a by-pass on both gas and air supply lines can be fitted.

Our considerations have so far been confined to the use of blast-furnace gas as fuel. Without doubt, in any power or blowing installation it would be politic to make provision for burning an alternative fuel. So far as the gas turbine is concerned, the alternative to blast-furnace or coke-oven gas is oil.

In the short survey we have made of the application of the gas turbine to power generation, and in the considerations which follow regarding its use for blast-furnace blowing, we have dealt conservatively with the operating efficiencies which we expect to obtain under practical working conditions. These will be seen to compare favourably with corresponding efficiencies for steam-driven power or blower plants commonly installed in iron and steel works. But it is probably true to say, particularly in the case of the blowing unit, that the overall reliability of the plant is of more importance than one or two points in efficiency. Accordingly when an engineer or his Board of Directors are faced with the question of new plant, and have the choice between the 'tried' and the 'untried,' unless the 'untried' has something spectacular to show in either first cost or efficiency, the choice naturally leads to the 'devil we know.'

The gas turbine makes no extravagant claim to greatly increased efficiency over the steam turbine. In first cost it will, in general, be less than combined boiler and steam turbine plant. Some saving will result in building and foundation costs. Its relatively-modest demands in water supply and quality are greatly in its favour. But its reliability under operating conditions has yet to be proved, and it is only with operating experience to draw upon that producer and user will be in a position to sell or buy with confidence.

There is no *a priori* reason, with the materials now available, and with conservative stressing and design, why this type of prime mover should not prove efficient and reliable as a 'long life' industrial unit. Conditions are favourable to its efficient and reliable development. It is therefore a matter of the utmost national importance that the closest co-operation should obtain between Government Bodies, Trade and Research Associations, steel companies, and turbine manufacturers to ensure that British engineers are given every opportunity to develop what promises to be an important factor in our future national economy.

The authors wish to express their appreciation of the invaluable assistance given by Messrs. Davey, Robson, and Hopper, and Miss Christie, of the Research and Development Staff, in the preparation of the calculations and diagrams used in the paper, and to Messrs. C. A. Parsons & Co., Ltd., for permission to publish it.

PART II—BLAST-FURNACE BLOWING APPLICATIONS

Section I—The Axial Blower

*By W. H. Gibson, B.Sc. (Durham)**

THE present practice of using a multistage centrifugal compressor driven by a steam turbine gives a satisfactory arrangement for meeting blast-furnace blowing demands. For example, if we consider a blast-furnace for which the normal blowing demand is 55,000 cu. ft./min. at 16½ lb./sq. in. (gauge), by carefully choosing the normal operating point (N.P.) on the centrifugal-compressor characteristic we can satisfy a maximum pressure condition of say, 48,000 cu. ft./min. at 21 lb./sq. in. (gauge) and can also allow for an increase in the blowing demand up to some 69,000 cu. ft./min. (*i.e.*, roughly a 25% increase above normal) at either of the two blast pressures mentioned. The centrifugal-compressor/steam-turbine combination will also give the low volumes and pressures required when blowing-in a new furnace and is able to meet the pressure and volume conditions demanded when the blast-furnace is working at reduced output.

In recent years, however, as a result of intensive fluid-dynamics research both in this country and on the Continent, the axial-flow compressor has been developed to give maximum efficiencies of the order of 84% over a considerable speed range. This efficiency is better than that of the best existing centrifugal compressors. So, apart from providing an introduction to the subsequent sections which deal with a particular type of axial compressor, some consideration is given in this section of the paper to the possibilities of the straight axial-flow compressor as a blast-furnace blower.

It is of interest at this point, to recall that although the first use of the steam turbine was for the driving of electric generators (for which its high speed made it specially suitable) its use as an axial compressor or as a means of driving an axial compressor was equally in the mind of the late Sir Charles Parsons, as is shown by the claims of his 1884 patents. Several axial blowers were built by Messrs. C. A. Parsons & Co., Ltd., as early as 1901, ranging in capacity from 3000 to 30,000 cu. ft./min. with delivery pressures of from 2 to 15 lb./sq. in. (gauge). However, as nothing was then known of the aerodynamical principles and data used today, these early blowers, which employed modified propeller sections, were relatively inefficient, attaining a maximum efficiency of about 55%. The axial-flow type of compressor was abandoned about 1909 in favour of the centrifugal compressor which was then proving more efficient.

This state of affairs regarding the axial compressor persisted in this country, except for a few researches, until 1935 or thereabouts, when renewed interest was taken in the axial compressor for driving large high-speed aeronautical wind tunnels and as the main component of an aircraft gas turbine. During the recent war the waxing interest in the application of the gas turbine to aircraft propulsion stimulated research and development in the principles relating to axial-compressor design. As an example of the intensity of this work it might be mentioned that in their investigations of high-speed air flow through cascades of compressor blading in the first high-speed wind tunnel to be employed in this country Messrs. C. A. Parsons & Co., Ltd., have made over 100,000 readings. Data obtained from these tests were used in the design and construction of the 10,000-cu. ft./min. compressor shown in Fig. 7. This compressor, employing 25 stages of blading and running at 6000 r.p.m., delivers at 41 lb./sq. in. (gauge). For an axial-flow blast-furnace compressor delivering at 16½ lb./sq. in. (gauge) we should, of course, require only about 10 stages of blading, and for an inhaled volume of 55,000 cu. ft./min. the speed would be correspondingly lower.

A detailed explanation of the design of industrial types of axial-flow compressors is outside the

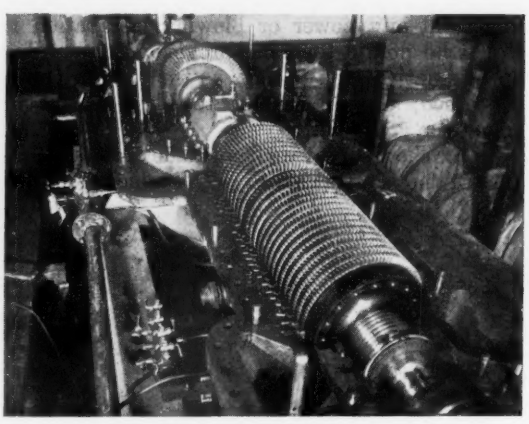


FIG. 7—Axial-flow compressor with cover removed

* Research Engineer, Messrs. C. A. Parsons & Co., Ltd.

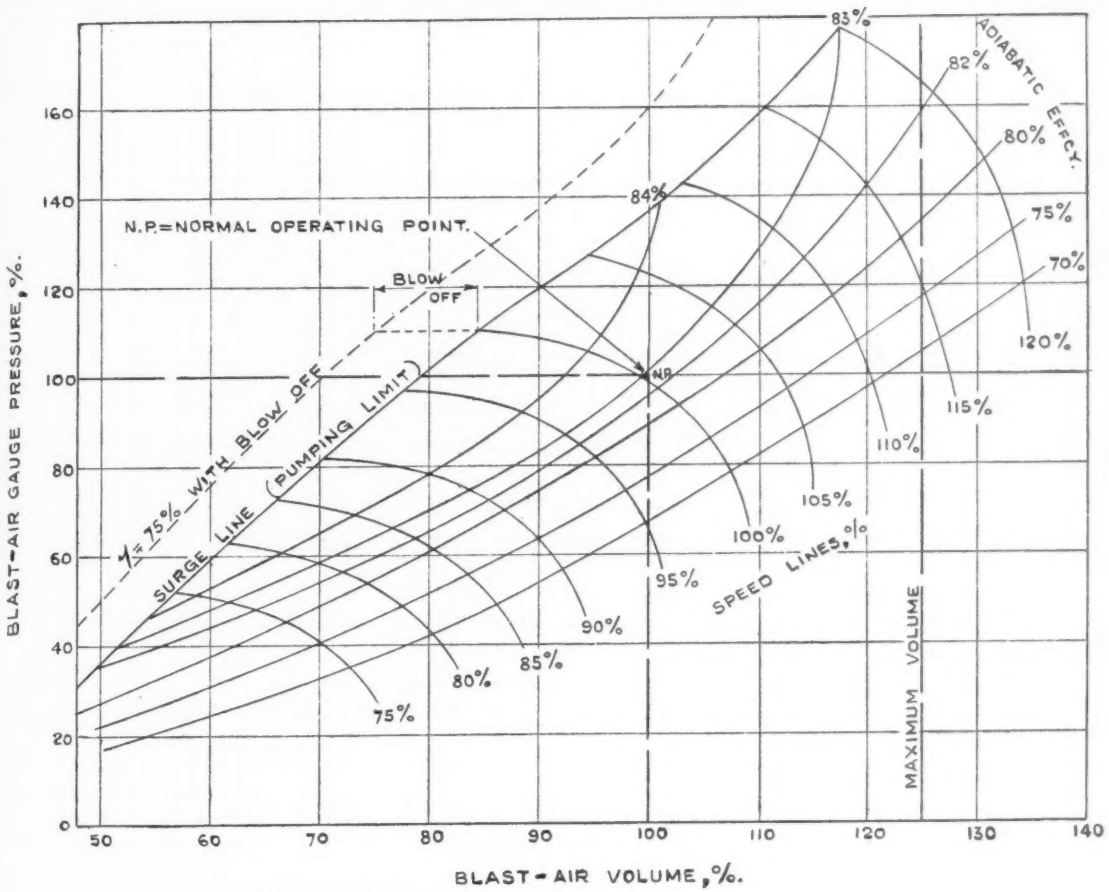


FIG. 8—Pressure/volume characteristic of axial-flow blast-furnace air compressor

scope of this paper. However, the method used is essentially the same as that employed in the design of axial compressors for aircraft gas turbines, so adequately described by Constant and Howell.* The normal speed of an axial compressor, if directly coupled, is generally fixed by the normal speed of the driving turbine (whether steam or gas), which is the more highly-stressed component of the plant. In heavy industrial steam- or gas-turbine practice, in view of the long life required from the machine, it is necessary to use much lower stresses and consequently lower speeds than are normally employed in aircraft axial compressors of similar volume flow and outlet pressure.

The use of such relatively-low speeds and stresses in heavy industrial axial compressors means, as noted above, that we require in general about 10 stages (1 stage = 1 moving row plus 1 stationary row) to deliver air at 16½ lb./sq. in. (gauge). The blades in the axial compressor must, for the attainment of high efficiency, be twisted throughout their length. Whatever the method of manufacture, this requirement entails considerable expense which is foreign to the inherent simplicity of the axial compressor. It is therefore, chiefly in seeking a combined aerodynamical and production solution to this problem that the design office and workshop are now engaged.

When considering compressor efficiency it is important to remember that the overall efficiency depends on the stage efficiency and compression ratio if we ignore the effect of losses at inlet and outlet from the compressor. Thus, taking a stage efficiency of 89%, for a compressoin ratio of 2, the overall blading efficiency will be about 86·5%, while for a higher compression ratio of 4 the overall blading efficiency will drop to about 85·5%.

* H. CONSTANT and A. R. HOWELL, *Proceedings of the Institution of Mechanical Engineers*, 1945, vol. 153, pp. 441.

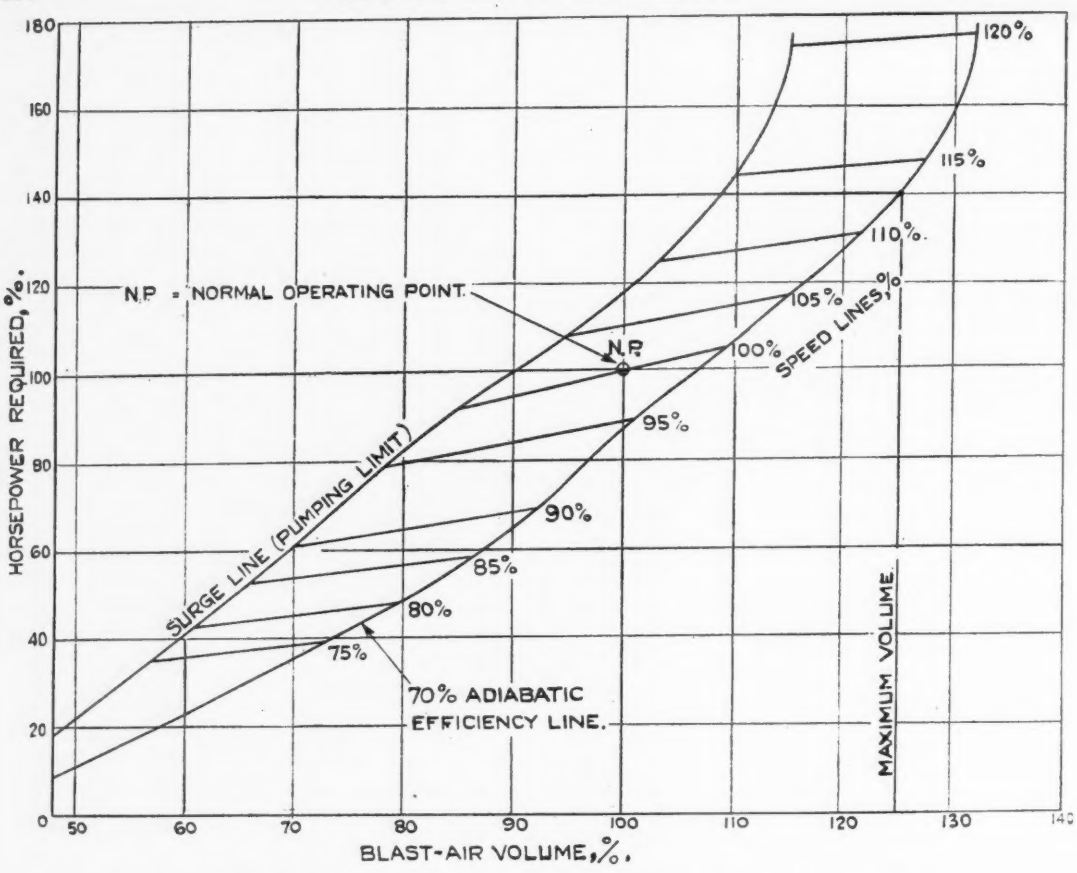


FIG. 9—Horse-power/volume characteristic of axial-flow blast-furnace air compressor

The operating characteristics of an axial blast-furnace blower are shown in Fig. 8. The blast-volume and blast-air gauge pressure scales are on a percentage basis. The normal operating point (N.P.), as for example 55,000 cu. ft./min. at 16½ lb./sq. in. (gauge), is chosen on the 100% speed line to give 100% blast volume and 100% blast-air pressure at 83% overall compressor efficiency.

If we assume a modern centrifugal blast-furnace air compressor to have a mean efficiency of 75% over the same range of blast-air volume, it will be seen that there is a considerable range of both pressure and volume up to the surge line, where the axial compressor is more efficient. For example, at a constant volume of 100%, the blast-air pressure as dictated by the condition of the furnace burden could vary from 78% to 137% of the normal pressure, whilst for a constant blast pressure of 100%, the volume can vary from an upper limit of 115% to a lower limit, the detailed consideration of which is extremely interesting. Taking the 100% speed line, we can move to the compressor surge line which is the natural pumping limit of the compressor. However, at this point the axial compressor is at its peak efficiency of about 84·5%, and if we require lower volumes at this pressure we can afford to blow off some 10% of the volume continuously, between the blower and the furnace, before the equivalent compressor efficiency falls to 75%. At this latter efficiency, as may be noted from Fig. 8, it is possible to deliver some 70% of the normal volume at the normal operating pressure. For blowing-in the blast-furnace, pressure blow-off would be required with a consequent low operating efficiency, but this is a short-term and infrequent operation.

Figure 9, showing percentage horse-power required to drive an axial compressor, indicates that to obtain a 25% increase on normal volume, a speed increase of 12·5% and a horse-power increase of 40% would be required. It is interesting to note that the power required to drive the compressor at constant speed increases only

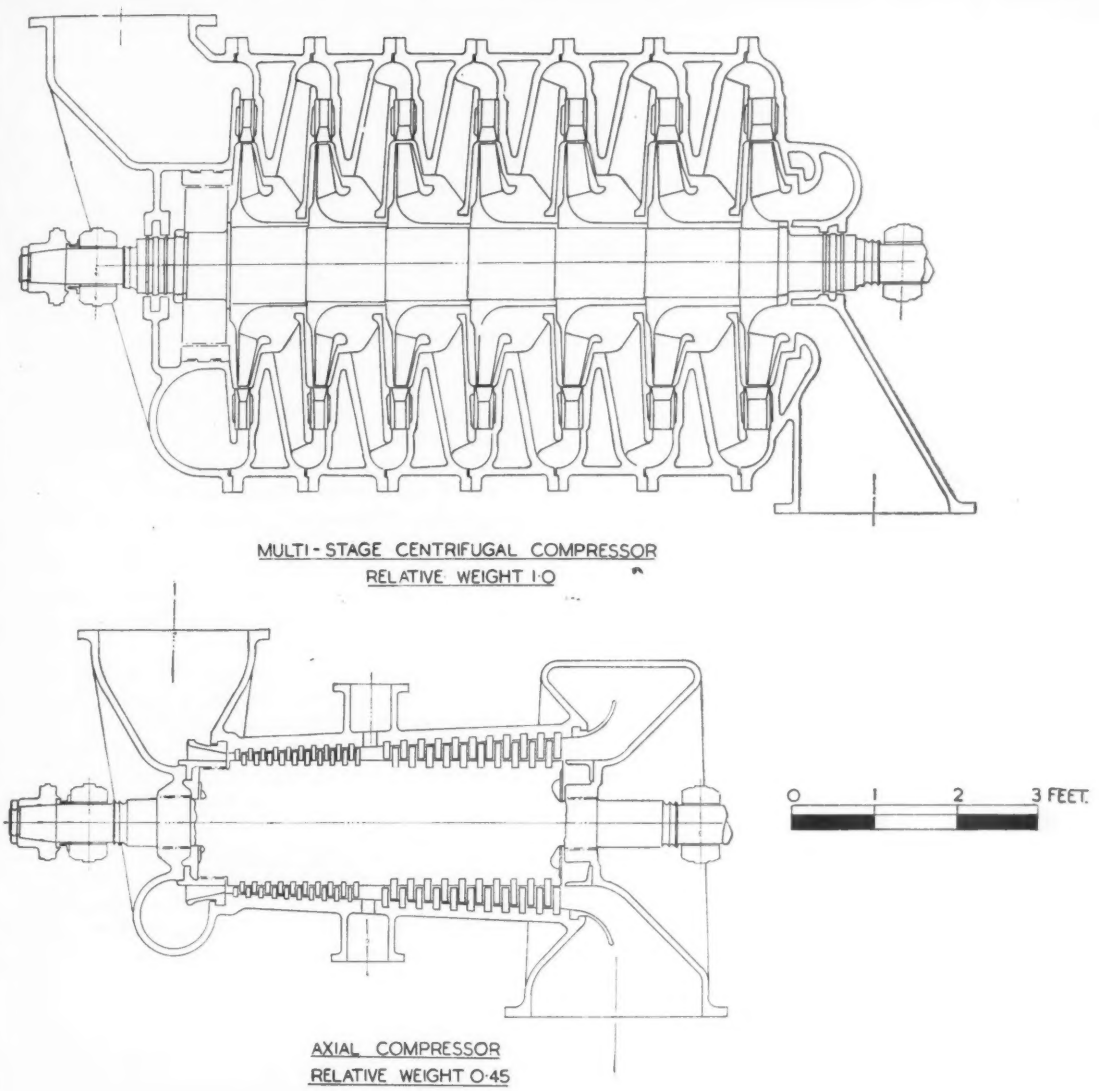


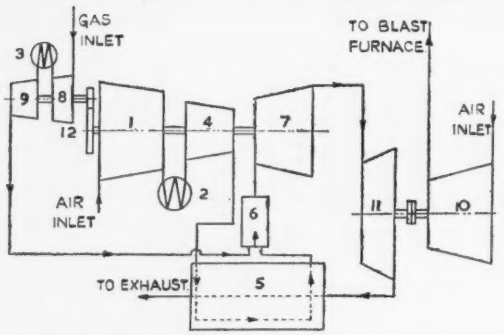
FIG. 10—Comparison of multi-stage centrifugal and axial compressors designed for same duty at same speed

slightly with increasing volume.

We have already discussed the factors influencing the design of an axial compressor, the results of which are clearly shown in Fig. 10, which compares a centrifugal and an axial compressor designed for the same duty at the same speed. Taking the weight of the centrifugal compressor as unity, the relative weight of the axial compressor is of the order of 0·45. Although the manufacturing costs of the high-efficiency blades, at least with present available processes, are high, the overall cost is likely to be considerably less than that of a centrifugal type for similar duty.

To summarize the foregoing we may say that, provided we are prepared to blow-off for a shorter or longer period depending on the furnace characteristics, the axial-flow-compressor characteristics provide a much wider pressure/volume operating range than is generally appreciated—a range which may in fact meet normal blast-furnace requirements. The efficiency over the whole range is equal to, and over a considerable portion of the range is appreciably better than, that given by a centrifugal blower.

As noted in Part I, the gas turbine has reached the stage where a simple unit conservatively designed as a long-life machine and using blast-furnace gas as fuel, has an overall thermal



1 = 1st-stage axial-flow air compressor
2 = Air intercooler
3 = Gas intercooler
4 = 2nd-stage axial-flow air compressor
5 = Heat exchanger
6 = Combustion chamber
7 = Main turbine
8 = 1st-stage gas compressor
9 = 2nd-stage gas compressor
10 = Axial or centrifugal B.F. air compressor
11 = Power turbine
12 = Step-up gearing to gas compressors

FIG. 11—Gas turbine with separate power turbine driving blast-furnace air compressor

efficiency of some 22%. It therefore demands consideration as an alternative to the steam turbine as a drive either for centrifugal or axial blast-furnace compressors.

In considering the application of the gas turbine to blast-furnace blowing, the simplest type of gas turbine we could contemplate for direct coupling to a centrifugal or axial blower is the single-shaft arrangement shown in Part I, Figs. 2 and 5. This arrangement, however, is unsuitable for driving a blast-furnace blower directly, because of the inherently-limited speed range of a gas turbine employing an axial compressor. Due to convergence of the turbine operating line with the main compressor surge line it is impossible to run the machine very much below 70% of the normal speed without bleeding the main compressor.

In order to be able to run a centrifugal or axial blast-furnace blower over its full speed range from zero to say, 115% of normal speed, we must consider an arrangement of the type shown diagrammatically in Fig. 11. In this two-shaft layout, the blast-furnace air compressor (10) is driven by a separate power turbine (11). The main compressor turbine unit (1, 4, 7) can operate continuously at practically constant efficiency over a speed range of 80–105% of its normal speed, with turbine inlet gas temperatures of about 1000° to 1200° F., respectively, while the power turbine operates from zero to 115% speed. When the power turbine is running synchronously at the speed for maximum efficiency, the overall efficiency of the plant varies from 22·5% to 24% over the normal range of operation. Unfortunately, as we have seen, in order to obtain flexibility of operation we have had to increase the number of main components with consequent increase in cost.

The question therefore arises, is it possible to combine the gas turbine with its many advantages, and the axial blowing compressor with its inherently high efficiency, without introducing the complication and increased cost of a two-line unit for the former and extensive bleeding of the latter ?

We believe that a single-shaft gas turbine coupled to a single bled axial compressor, which meets both blast-furnace and combustion-air requirements, offers an attractive solution, and in the following sections of the paper the question is dealt with in some detail.

Section II—The Bled-Axial Gas-Turbine Blower

*By J. W. Railly, B.Sc. (Eng.)**

THE objections to the use of the gas turbine coupled to an axial blower have been dealt with in Part II, Section I., of the paper.

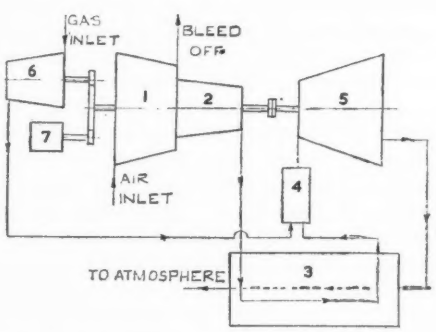
The combination involves a two-line turbine unit and continuous compressor blow-off if provision has to be made for long-period working with volumes appreciably lower than normal at or near normal pressure. Both difficulties may be overcome by coupling a simple single-line gas turbine to a bled axial compressor which at one and the same time serves to supply blast-furnace and combustion air. A diagrammatic arrangement of this type of plant is shown in Fig. 12, where the first stage of the compressor handles the air going to the blast-furnace, and the whole of the air which passes to the turbine. This arrangement is termed the ' bled-axial ' plant. In Fig. 12, (1) is the first stage of compression, and (2) the second stage of compression in which the turbine air is further compressed. This air leaves the compressor and enters the heat exchanger (3) where heat is received from the hot exhaust gases from the turbine. The hot air then enters the combustion chamber (4) in which blast-furnace gas is burnt in the air stream. The blast-furnace gas must first be compressed in a separate gas compressor (6)

* Research Engineer, Messrs. C. A. Parsons & Co., Ltd.

which is geared to the main shaft and runs at a speed more consistent with the much smaller mass flow which it passes. The hot burnt gases then pass through the turbine (4) which supplies the power for the air and gas compressors. The hot exhaust gas in passing to atmosphere through the heat exchanger gives up its heat to the air entering the combustion chamber.

The advantage of this arrangement is two-fold. Firstly the incorporation of the blast compressor within, as it were, the compressor for the gas turbine, leads in the first place to economy in production cost and space, and secondly, as we shall observe, gives a wide range of operation at good efficiency.

Both of these advantages follow by virtue of the large volume of air handled by the gas turbine and the fact that the amount bled off to the blast-furnace constitutes only a fraction of the total volume handled by the compressor. From the point of view of the compressor design, the additional mass flow which is passed to the blast-furnace requires a machine only slightly larger than would normally be required for the gas turbine alone. Throughout this section of the paper we deal for convenience with a plant supplying as its normal condition 55,000 cu. ft./min. at 16½ lb./sq. in. (gauge), and 66,000 cu. ft./min. at 16 lb./sq. in. (gauge) as the maximum volume condition, with 48,000 cu. ft./min. at 21 lb./sq. in. (gauge) as the maximum pressure condition. These conditions do not in any way represent the limit of this type of plant. It is in fact, well suited to the larger volumes now being considered in blast-furnace operation. The gas turbine in the design we have chosen operates with a normal



1 = 1st-stage axial-flow air compressor
2 = 2nd-stage axial-flow air compressor
3 = Heat exchanger
4 = Combustion chamber
5 = Turbine
6 = Gas compressor
7 = Starting motor

FIG. 12—Diagrammatic arrangement of bled-axial gas-turbine plant

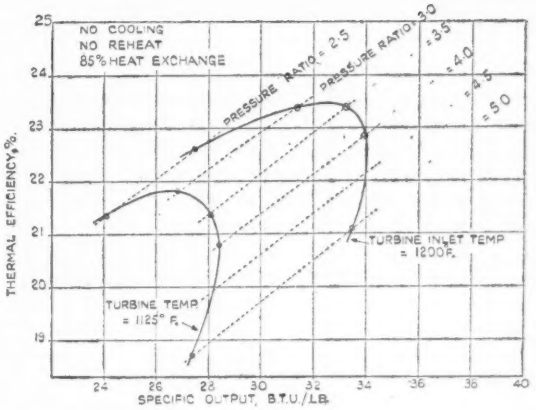


FIG. 13—Effect of pressure ratio and turbine inlet temperature upon the thermal efficiency and specific output

inlet temperature of about 1100° F., and the cold air leaving the compressor and entering the heat exchanger experiences a temperature rise of about 80% of the difference between the turbine exhaust temperature and the compressor outlet temperature. These two conditions demand a certain optimum overall pressure ratio for the best thermal efficiency. If a lower value of this ratio is adopted, then the thermal efficiency is reduced, and similarly if the pressure ratio is increased above this value then there is a fall in thermal efficiency. This effect is shown in Fig. 13, where the thermal efficiencies are plotted against specific output for a simple blast-furnace gas-turbine plant without intercooling or reheating, for two values of turbine inlet temperature. The optimum pressure ratio for 1125° F. is about 3, and for 1200° F. is about 3·5.

In the plant we have considered, the optimum overall pressure ratio is 3, *i.e.*, the compressor delivery pressure is about 30 lb./sq. in. (gauge). This necessitates a special casing for the axial compressor so that the air which passes to the blast-furnace is bled-off at a point in the compression where the pressure is about 16 lb./sq. in. (gauge). This is best accomplished by the provision of an annular break in the casing and a separate outlet volute. However, if steel manufacturers should choose to operate their blast-furnaces at higher blast pressures—of the order of 30 lb./sq. in. (gauge) at the normal condition—the air could be supplied without the provision of this second outlet volute.

We have already mentioned that the gas turbine handles very large volumes of air—much larger than the volume of air handled by an oil engine of the same power output—and this is equivalent to saying that the *specific output* (*i.e.*, output per lb. of air) for a gas turbine is smaller. Naturally

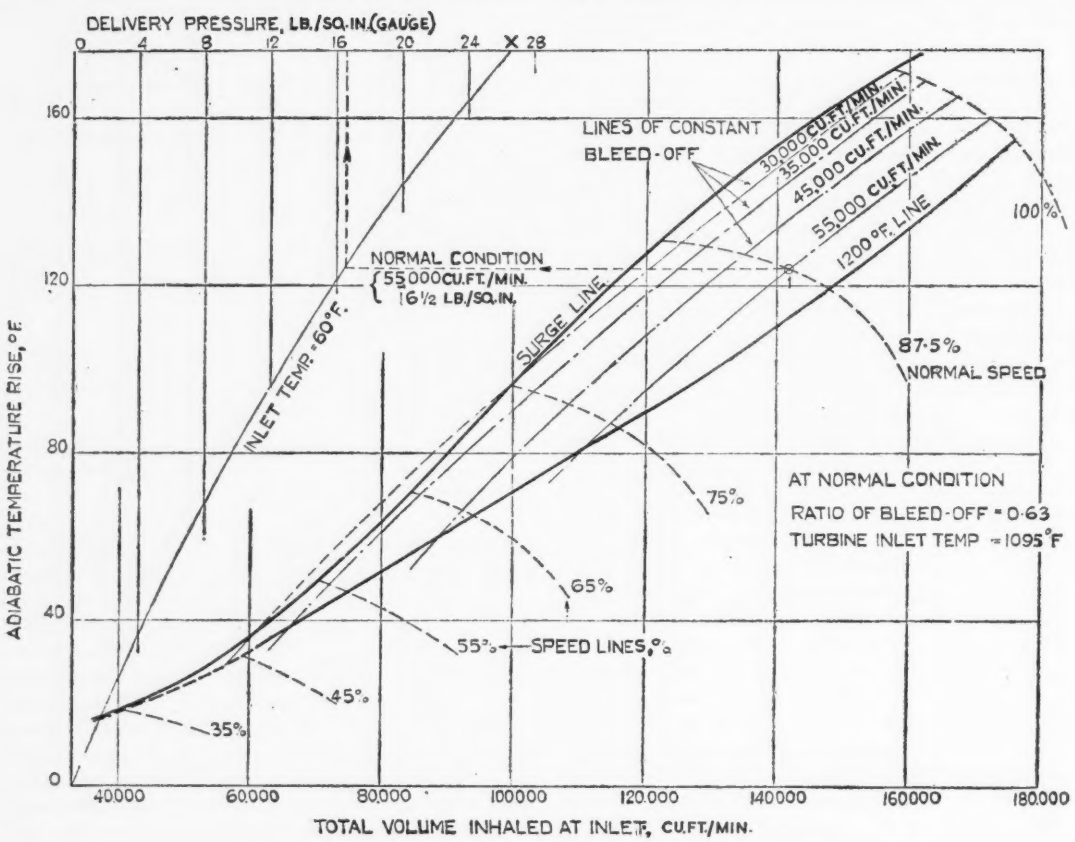


FIG. 14—Characteristics of first stage of bled axial blower

as the specific output of the gas turbine is increased the weight of air handled for a given power output is reduced, and the size of the machines are thereby made smaller. This is obviously a desirable feature, and we have examined the value of ways of increasing the specific output in connection with the bled-axial gas turbine for blast-furnace blowing. The specific output may be increased by raising the turbine inlet temperature, but for reasons which we will show later we are restricted in this direction. A second method of increasing the specific output is to introduce cooling during the compression process. This has the effect of reducing considerably the input to the compressor although it lowers the compressor outlet temperature and hence the increase in thermal efficiency is not relatively so great as the increase in specific output. For the plant under consideration one stage of intercooling (other conditions remaining constant) would increase the specific output by about 36% and the efficiency by 7%. However, in the case of a gas turbine compressing blast-furnace gas as fuel, the ratio gas-quantity/air-quantity increases with specific output, and this places a larger proportion of the compression work on the relatively inefficient gas compressor. Again, as the steelmaker would have to supply a considerable amount of cooling water and the designer would have to provide two separate compressor stages and a large intercooler, the concession in efficiency for the gain in simplicity is considered worth while.

The addition of the complication of reheat, *i.e.*, the partition of the expansion of the hot gases into two turbine stages with an intermediate reheating combustion chamber would give only a slight increase in thermal efficiency at the low compression ratios used, and this consideration together with the implication of the extra turbine and combustion chamber hardly justifies such an elaboration.

In the case of the bled-axial plant an increase in specific output has a further effect. Since the mass flow is decreased by increase in the specific output, the mass flow bled off to the furnace will constitute a larger proportion of the turbine mass flow. Thus if H_{c2} is the work done per pound of blast air in the first stage of compression, and if

S is the specific output of the plant in ft.lb./lb. of turbine air flow, then the ratio of bleed-off, b, is given by :

$$b = \frac{S}{H_{c2}} = \frac{\text{Bleed-off flow}}{\text{Turbine air flow}}.$$

The effect of this ratio on the shape of the characteristics will be more marked the higher the value of b ; obviously the higher the value of b at the normal condition, the greater the effect of a change of the volume to the blast-furnace on the operation of the gas turbine. In general, the effect of seeking to improve the specific output and efficiency beyond a certain datum level is to decrease the working range over which the compressor can operate without having recourse to bleeding between compressor outlet and blast-furnace.

For the determination of the operating characteristics, resort must be made to lengthy part-load calculations to study the effect on operation and efficiency of variation in blast-air volume and delivery pressure. For this work it is necessary to have available axial-flow compressor characteristic curves for the type and design of compressor to be used.

In Fig. 14 are shown the characteristics of the first stage of compression (*i.e.*, the part (1) of Fig. 12). The inhaled volume is plotted as horizontal ordinate against the adiabatic temperature rise in ° F. as vertical ordinate. This latter is immediately convertible to delivery pressure for the given initial temperature by the line OX drawn on the left. Constant-speed lines are shown dotted, and speeds are given as percentages of a nominal maximum speed of 100%. It can readily be seen (Fig. 14) that for a given value (say 55,000 cu. ft./min.) of blast-air volume and a given speed, say 87·5%, there is only one operating point on this speed-line (*i.e.*, point 1) and only one possible turbine inlet temperature (in this case 1095° F.). If we displace this point to the right the compressor will absorb more power and the delivery pressure will tend to fall, tending to reduce the speed and to reduce the flow to the turbine. To obtain equilibrium between compressor input and turbine output (so that the speed remains the same), the turbine inlet temperature must increase. This tends to reduce the mass-flow to the turbine so that for equilibrium there must be a greater flow to the blast-furnace. The net result is a new bleed-off flow, a new operating point, and a new turbine inlet temperature. It will also be observed that for a 5% increase in the total inhaled volume there is a 22% increase in the volume to the blast-furnace, so that the increase in bleed-off volume is compounded of an increase in the total flow and a decrease in the turbine flow. This effect is greater the smaller the ratio of bleed-off to turbine air flow.

Referring again to Fig. 14, we can see the wide range of volume delivered to the furnace covered within the comparatively narrow operating range of the compressor itself. The heavy line denoted by 1200° F. is the upper limit set by our restriction on maximum operating temperature. Thus, operation is restricted to the left of this line and above it. Again, operation is limited on the left by the surge point of the first stage of the compressor, so that an anti-surge device should be fitted, as with centrifugal compressors, to maintain the bleed-off at about 30,000 cu. ft./min. by by-passing through a blow-off valve fitted in the pipe leading towards the blast-furnace. The characteristics of the second stage of the compressor which compresses the turbine air have not been shown, as nowhere do they limit the operation of the plant, the limitations being solely the surge line of the first stage and the maximum allowable turbine inlet temperature. Before referring to Fig. 15 it should be noted that lines of constant volume run parallel to the surge line, thus providing a very wide range of pressure delivery. At the lower speeds, however, further reduction in pressure cannot be achieved by reduction in speed. Thus, if we are operating with a constant volume regulator set at say, 55,000 cu. ft./min., then at 72·5% speed when the delivery pressure is 9·7 lb./sq. in. (gauge), the maximum turbine temperature of 1200° F. is attained. This effect is shown more clearly in Fig. 15 where bleed-off to the furnace has been plotted as abscissa against delivery pressure as ordinate for various speeds. This characteristic allows comparison with the characteristics of conventional centrifugal blast-furnace blowers. Thus constant speed lines are very nearly constant pressure lines. However, the turbine inlet temperature limitations which have been superimposed, indicate the difference between the characteristic and those of centrifugal blowers. For example, where a volume of 55,000 cu. ft./min. can be delivered by a centrifugal blower at delivery pressures down to zero by dropping the speed of the steam turbine, in this case delivery pressure below 9·7 lb./sq. in. (gauge) can only be obtained at this volume by throttling the blast air at outlet. Since it is unlikely that long-period operation is necessary at such volumes and pressures, this should not constitute a serious obstacle to operation. The only question is, what method should be used to operate safely at these low speeds and high volumes ?

This matter will be dealt with in detail in Section III (Part II) of the paper. Suffice it here to say that the choice lies between automatic devices to prevent the speed being reduced below

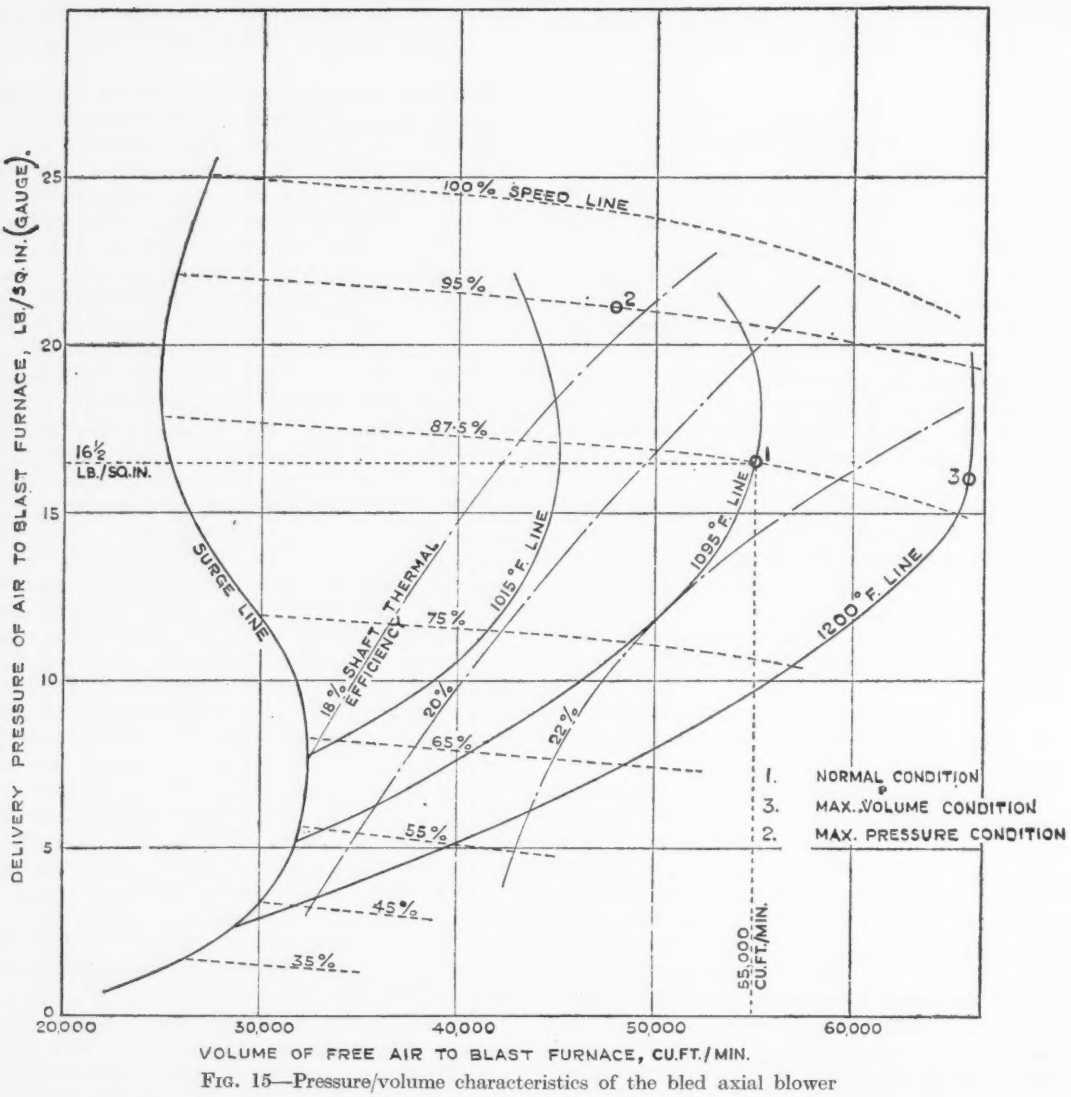


FIG. 15—Pressure/volume characteristics of the bled axial blower

that limit at which, for a given blast volume, the maximum temperature is attained, or a warning device which indicates that the maximum temperature limit has been reached for a given setting of the constant volume regulator, and which enables the operator himself to throttle the outlet. Accordingly, if the throttle valve in the outlet is closed the volume will tend to be decreased and the constant volume regulator will raise the speed of the plant.

We may further observe from Fig. 15 the trend of thermal efficiency and turbine inlet temperature caused by variation of blast volume and delivery pressure. In order to obtain the maximum volume condition (66,000 cu. ft./min. at 16 lb./sq. in., gauge), the turbine inlet temperature must be raised to 1200° F., and if this is regarded as our maximum operating temperature then the normal condition requires a turbine inlet temperature not greater than 1095° F. Hence, the more provision is made for volume in excess of normal, the more the turbine inlet temperature at the normal condition must be lowered in relation to the maximum operating temperature. This represents a potential fall in efficiency, as the lower the operating temperature the lower the thermal efficiency. This fact must be borne in mind in considerations of this type of plant for blast-furnace blowing. At loads other than those considered above, the general trend in thermal efficiency can be observed from Fig. 15. Thus for low pressures and high volumes the efficiencies

and temperatures are at their maximum, while the reverse applies for high pressures and low volumes.

There is no reason to believe that the upper-operating turbine inlet temperature of 1300° F. used in this discussion will not be exceeded for long-period working when new materials become available and the problems of blade and rotor cooling have been solved. If the turbine inlet temperature is increased at the normal condition to 1175° F., this will require about 1280° F. at the maximum volume condition. The thermal efficiency will be increased at normal condition, but the operating range will be a little more constricted as a result of the higher bleed-off ratio (0·77 as against 0·63 for the plant of Fig. 14). Thus the bleed-off volume at which the surge point occurs is 5000 cu. ft./min. higher, and the lower limit of delivery pressure for the bleed-off volume of 55,000 cu. ft./min. is about 13 lb./sq. in. (gauge). Thus broadly speaking, since higher thermal efficiencies go hand-in-hand with a decrease in the mass-flow for a given output, higher efficiencies are accompanied by a progressive constriction of the operating range.

From these results it will be clear that while increased output and efficiency are very desirable, the characteristics of the bled-axial gas-turbine compressor ask for the highest possible turbine mass flow (*i.e.*, the lowest bleed-off ratios) consistent with good efficiency.

In conclusion we may recapitulate the advantages of the bled-axial compressor for blast-furnace blowing.

Firstly, there is considerable economy of machinery and space, there being only, on one shaft, a compressor and a turbine and, coupled by gearing to this shaft, the smaller gas compressor and a starting motor (which in the plant considered above would be of the order of 200 h.p.).

Secondly, in view of the lower efficiencies of present-day centrifugal blast-furnace blowers, the overall thermal efficiency obtained by the combination of gas turbine and axial compressor compares favourably with alternative power and blowing systems.

Thirdly, the bled-axial gas-turbine plant is very little inferior in regard to operating range to the steam-turbine-driven centrifugal blower.

Section III—Operation and Control of the Bled-Axial Gas-Turbine Blower

*By R. G. Voysey, A.C.G.I., D.I.C., Wh.Sch., A.M.I.Mech.E.**

Comparison has been made between the various alternatives, and the balance is generally in favour of the bled-axial type of blower.

A proposed lay-out for a plant of the type shown diagrammatically in Fig. 12, Section II, is shown in Fig. 16 from which the relative dimensions and disposition of the components may be clearly seen.

Assuming reliability to be axiomatic, then the two most important factors from the blast-furnace operator's point of view will be economy and flexibility.

If all fuels were costed on their available calorific value then economy would rest on thermal efficiency. Figure 17 shows the pressure/volume operating characteristics with superimposed lines of thermal efficiency and fuel consumption. The thermal efficiencies refer to the shaft power and do not include the compressor efficiencies which will, however, be high, since an axial compressor is being used. As outlined in Section II, the simplicity of the chosen cycle, the nature of the fuel, the avoidance of the need for cooling water, and other factors, all tend to make the efficiency of this application of the gas turbine lower than in its application to other fields, but the overall efficiency, including the favourable effect of using an axial blower, is still attractive when compared with other types of blowing units. The maximum value shown is 21% based on standard atmospheric conditions. A steam turbo-driven, uncooled, centrifugal blower would require a thermal efficiency of some 24% from fuel to turbine shaft for an equal overall blowing efficiency, and this figure would not be easily achieved in a steelworks where there is usually insufficient cold water to satisfy the total demand.

Again referring to Fig. 17, it will be seen that the variation in efficiency over the operating range is not too great. This variation is best discussed for each special case of blowing.

Blast-furnace requirements vary, but five separate cases of blast demand can be distinguished. The most important case is with the

* Engineer in Charge, Gas Turbine Research, Messrs. C. A. Parsons & Co., Ltd.

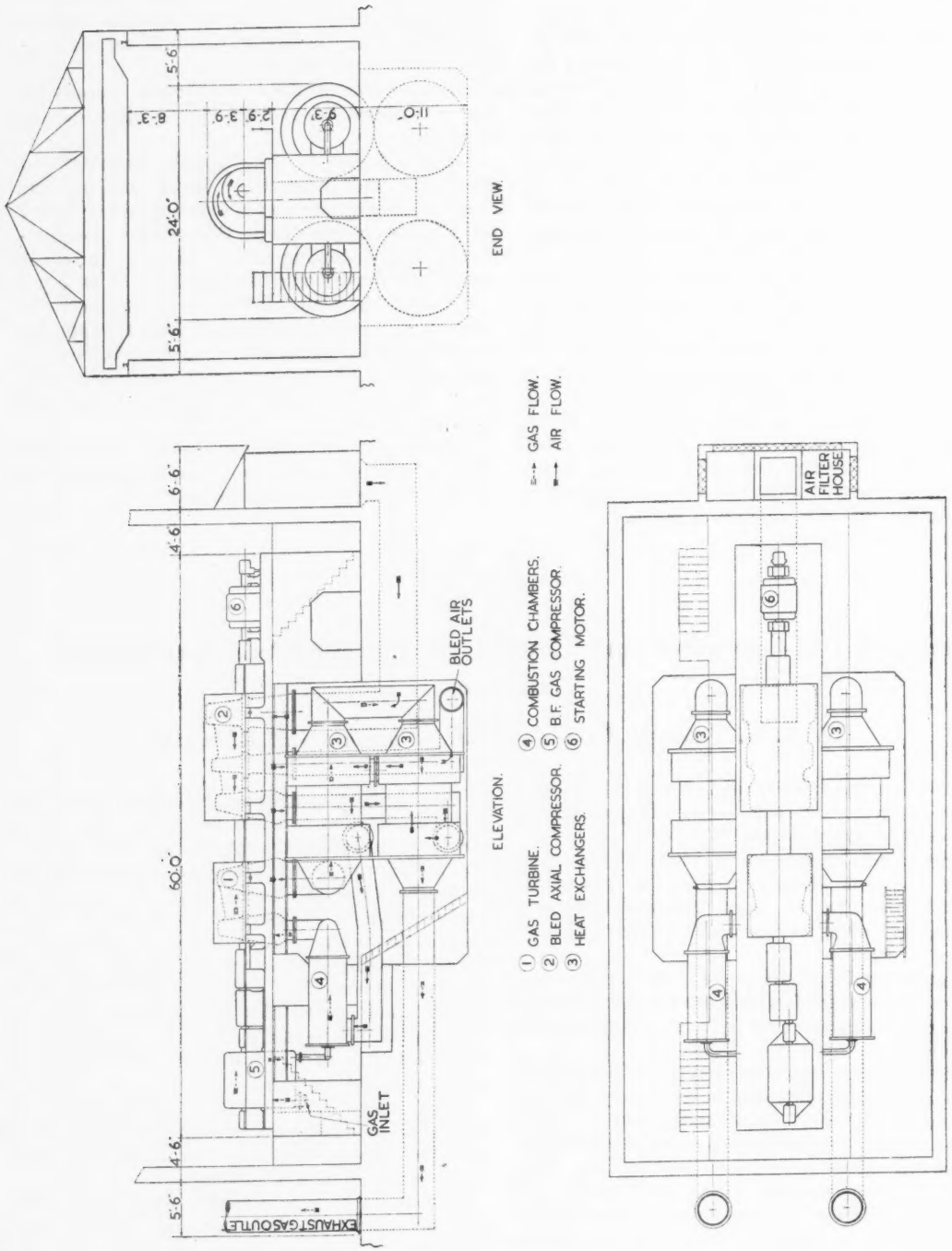


Fig. 16—Station layout of 50,000-cu. ft./min. gas turbo-blower

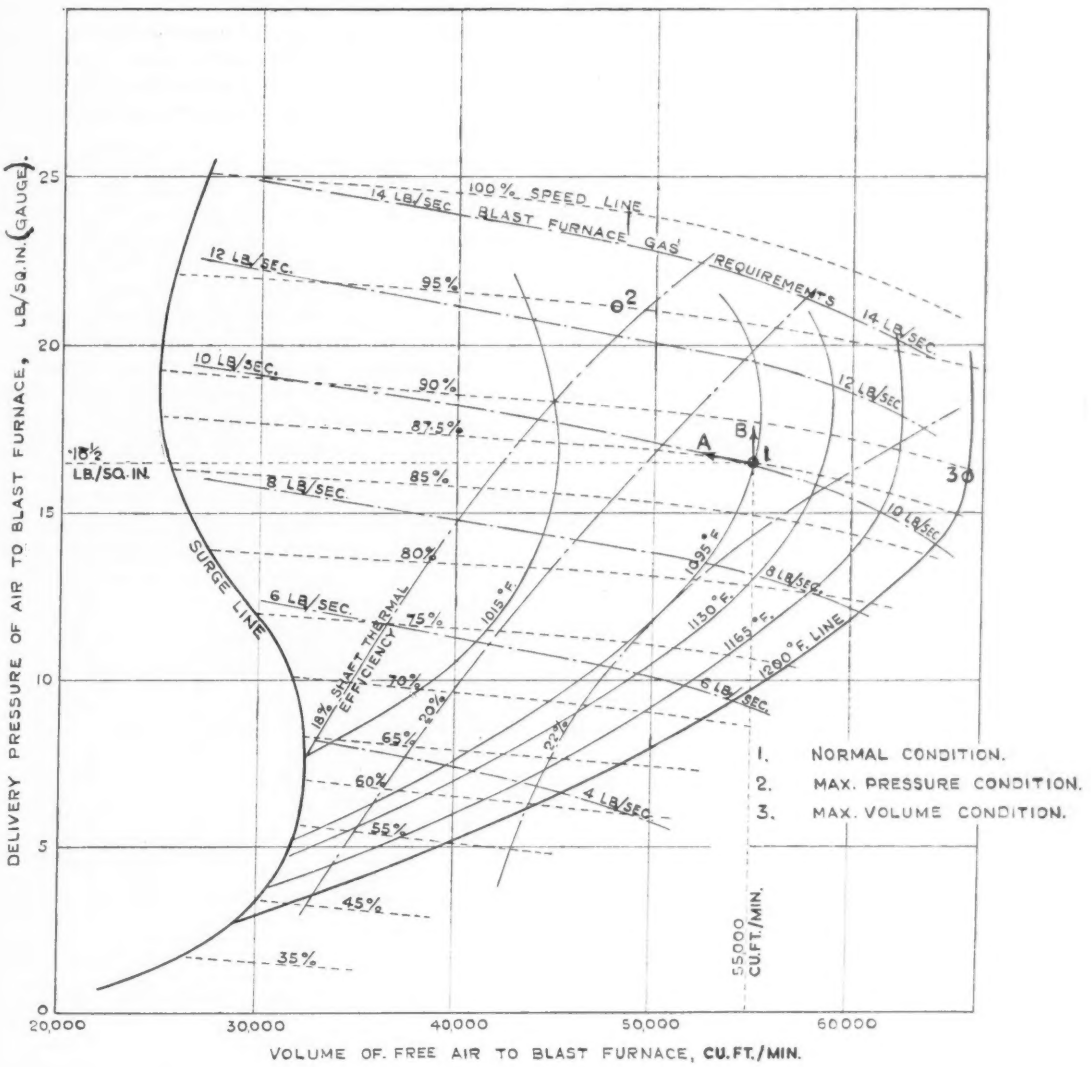


FIG. 17—Pressure and efficiency characteristics of the bled axial blower

furnace operating 'normally,' *i.e.*, with a certain volume of air passing per minute and with a certain blast pressure at the tuyeres. These values have been assumed as 55,000 cu. ft./min. and 16½ lb./sq. in., forming point 1 on the characteristics of Fig. 17. Such operation should, with only slight variations of flow and pressure, occupy most of the working time. Inevitably, and dependent on the furnace factors, there will be slight adjustments required of the turbine control apparatus to cope with tendencies to drift away from the state of constant volume of blast. The most exaggerated example of this is with a hanging charge, and it has been assumed for this second important mode of working that the blast pressure will rise to 21 lb./sq. in. (gauge) if the throughput falls to 48,000 cu. ft./min. This is point 2 on the characteristic. With wear and wasting away of the furnace lining the effective capacity of the furnace will rise and the situation may exist, immediately before relining, of a blast demand of 66,000 cu. ft./min. at 16 lb./sq. in.

PLAN.

FIG. 16—Station layout of 50,000-cu. ft./min. gas turbo-blower

This forms point 3 on the characteristic. This condition will have its own special low-volume high-pressure demands for the ' hanging charge ' case, but these demands are easily met and will not be considered further.

The fourth case of blast requirement occurs when we imagine the hanging charge to be so obstinate as to require the withdrawal for a fraction of a minute of the full blast pressure.

The fifth set of requirements are those for the blowing-in of a newly-prepared furnace involving low pressures, *c.* 5 lb./sq. in., and low flows, *c.* 10,000 to 15,000 cu. ft./min. for the furnace envisaged.

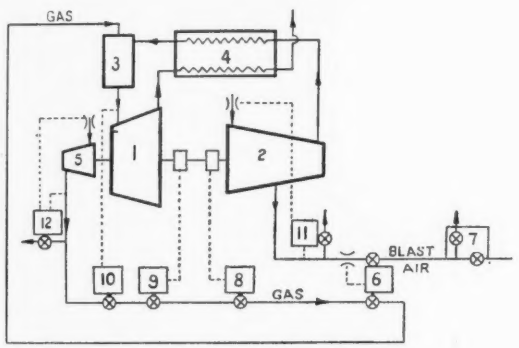
We may say in brief, that cases 1, 2, and 3 can be accommodated within the normal characteristics, that case 4 can be met, exactly as with steam-driven blowers, by a suitably-designed ' snort ' or bleeding valve, and that case 5 can be met only by bleeding and slightly throttling the blower for blowing-in the furnace. This latter is inferior to existing practice with turbo-driven centrifugal blowers, but only a very small fraction of the lifetime of the furnace is spent in ' blowing-in ' and the loss of efficiency by bleeding should be tolerable.

Before proceeding to discuss the important cases 1, 2, and 3, it will be as well to complete discussion of cases 4 and 5. Examination of the blowing characteristics of Fig. 17 will show that they are bounded at the top by the allowable speed of the blower, at the right and bottom by the restrictions on the highest operating temperature for the turbine, and at the left by the surge line.

Considering case 4, *i.e.*, the temporary withdrawal of full blast to secure a drop of the hanging charge, the problem is precisely that met with the steam-driven centrifugal blower. The blast must be withdrawn quickly, held at reduced level for a time at the furnace operator's discretion, and restored promptly when desired. With a steam-driven plant this case can be met in either of two ways. If the turbine is left on constant-speed governor control, a design of snort valve which throttles the inlet to the furnace at the same time as it bleeds the air from the main, will give the required low pressures and volumes without seriously disturbing the normal delivery conditions at the turbine. Alternatively, if constant-volume control is provided, the snort valve is simply a bleed valve which overloads the blower and leaves the constant-volume control to reduce the speed, and hence the pressure of the set, to a suitable value.

The ideal form of snort control with the gas turbine is to employ constant-volume control but to relieve the constant-volume control of the necessity of markedly lowering the speed of the set, by using a snort valve similar to that normally employed for constant-speed governing, *i.e.*, a combined throttle-and-bleed valve. If this were not done, the lowering of speed following from simple bleeding of the main might lower the operating point to the temperature limitation which forms the bottom boundary of the characteristic in Fig. 17.

Considering now case 5, *i.e.*, the blowing-in period, neither the low pressure nor volume requirements can be completely met by lowering the speed. It will be seen that a pressure as low as 5 lb./sq. in. from the blower would risk infringement of the high-temperature limitation. A pressure of 8 lb./sq. in. allows a bigger margin between the limits of surge and turbine temperature. Similarly the low volume of 10,000 cu. ft./min. is definitely in the surge region. The snort valve might be employed to secure the conditions with a mixture of throttling and bleeding, but it is undesirable to confuse the furnaceman's hand-operated valve with an automatic servo-operated control for safeguarding the plant. It is preferable to employ a throttle to lower the pressures, and



CONTROL SENSING LINKS SHOWN THUS - - - -
AIR & GAS VALVES SHOWN THUS ⊗
CONTROLS ARE OIL-SERVO OPERATED EXCEPT Nº 7

Engine components :
1 = Gas turbine
2 = Axial compressor
3 = Combustion chamber
4 = Heat exchanger
5 = Gas compressor

Control units :	Operated by :
6 = Constant-mass blast control	Blast flow and density
7 = Furnace snort valve	Manually
8 = Top-speed governor	Turbine shaft speed
9 = Overspeed trip	,, ,, ,,
10 = Top-temperature control	Turbine inlet temperature
11 = Antisurge valve	Air-inlet flow and outlet pressure
12 = ,, ,,	Gas-inlet flow and outlet pressure

FIG. 18—Control scheme for bled-axial gas-turbine blower

instal an antisurge valve to safeguard the flow. The procedure would then be to set the constant-volume control at 'minimum' operation which would lower the speed to say 65%. The throttle would be set to lower the 8 lb./sq. in. available to the desired pressure, say 5 lb./sq. in., and the antisurge valve would bleed the necessary excess air to maintain stable operation.

The discussion of cases 4 and 5 has served to introduce the necessary controls for the unit. Referring to Fig. 18, these can be enumerated as follows:

A. A 'snort' valve manually operated by the furnaceman. This is essentially a diverting valve allowing the furnace-blowing requirements to be met without marked lowering of the turbine speed. It is installed, as normally, just before the stoves.

B. An antisurge valve for both air and gas compressors, using the small pressure drop across the inlet to the compressor as a measure of inlet flow, and compounding this with a pressure taken from the blower to establish a safety line within the surge line. For points to the left of this line a bleed valve would be opened so that the surge limit was never reached.

C. A constant-volume governor using the pressure drop across a slight restriction in the blast bleed line from the axial compressor to adjust the fuel supply (by oil servo) to keep the volume of bled air constant. It would become necessary here to employ a refinement which rarely arises with existing blowing plant. The basic need of the blast-furnace is probably constant mass flow and not constant volume, and therefore changing barometer and temperature should correct the 'constant volume' meter. Although only a refinement in cases where the constant-volume control is operated by the atmospheric inlet to the compressor, the necessity here for placing the constant-volume control orifice in the bleed outlet, where widely varying pressures and temperatures are met, makes it desirable to correct its operation for variation of density. This is easily done by compounding the operation of the constant-volume control with the pressure produced by a constant-speed fan drawing and returning air to the bleed outlet and, therefore, sensitive to the density there.

D. A constant-speed governor which is employed only to limit the top speed of the blower by over-riding the attempt of the constant-volume control to push air through a badly-stiffened charge.

E. The normal overspeed trip fitted to turbine machinery.

F. A top temperature control set to over-ride all governors in the event of the maximum operating temperature being exceeded for more than a few seconds.

Controls *C*, *D*, *E*, and *F* all manipulate the fuel supply.

The discussion of operating conditions 1, 2, and 3 (*see* Fig. 17) is now quite straightforward. All are within the normal operating characteristic. The only problem is to secure optimum efficiency. Maximum efficiency at any given blower speed is given by maximum temperature which corresponds to maximum delivery volume. The optimum, therefore, is at maximum output. The designer must reserve his maximum temperature limitation for the condition of increased hearth size (point 3) and there is a slight loss of efficiency at 'normal' operation (point 1). However, the lower operating temperature there gives an increased factor of reliability and is of use for countering the effect of high inlet temperatures at some time during the day and year.

The latter effect can be accommodated in this general fashion because, within such narrow excursions of temperature, high turbine temperatures have a cumulative effect through the mechanism of creep rather than a definite failure of the material.

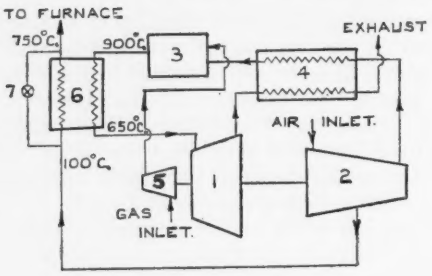
The governing characteristics with the constant-volume gear in the region of points 1, 2, and 3 on Fig. 17, are similar to those of a steam-driven blower. A sudden slight blockage of the furnace causes an instantaneous tendency to travel along a constant fuel line to slightly higher speeds and pressure. This is in the direction of the arrow 1–A. The constant-volume gear would quickly come into action, and the operating point would actually move in the path of the arrow 1–B on Fig. 17.

Increase of size of the furnace hearth will move 'normal' operation of the plant to the right, towards larger volumes, higher turbine temperatures, and higher thermal efficiencies.

Future Possibilities

Having dealt with what appear to be the most practical applications of the gas turbine to blast-furnace blowing practice, it is of interest in conclusion to consider some more speculative possibilities. These have already received considerable attention in the literature, and are generally directed towards eliminating or reducing the size of blast stoves.

Thus we may substitute a heat exchanger for the stove and do all the combustion both for gas-turbine blower and blast heating in one combustion chamber, under pressure. The heating side of the heat exchanger is connected between this combustion chamber and the gas-turbine unit, the other side of the heat exchanger carries the blast air to be warmed. It will be noted that a higher fuel ratio and a higher temperature is employed in this than in the normal combustion chamber, but, excluding mechanical problems, it will be sufficient to ensure that conditions (gas flow, pressure, and temperature) at the inlet to the turbine are as before the introduction of the heat exchanger. The slightly different combustion products will have substantially the same specific heat, and the gas turbine will operate in its normal way with the same rejection of exhaust heat. The advantage of this scheme is the saving of heat that would otherwise be rejected in the



1 = Gas turbine
2 = Bled-axial compressor
3 = Combustion chamber
4 = Exhaust heat exchanger
5 = Gas compressor
6 = Heat exchanger, replacing stove
7 = By-pass valve

FIG. 19—Bled-axial gas-turbine blower scheme using heat exchanger in place of stove

exhaust gases from the Cowper stove. The unavoidable pressure-drop losses in the heat exchanger might be balanced against the usual losses of pumping air and gas to the Cowper stoves. A diagram of the cycle of operation is shown in Fig. 19.

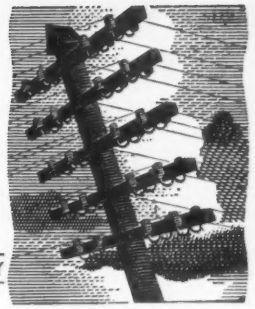
The tubular-type heat exchanger would lose a negligible quantity of heat, but the Cowper stove might lose 20%, and there would thus be a 20% cut in the blast-heating costs and gas demands. If we place this on a basis of total blast cost, *i.e.*, include the pumping work in both cases, the saving is still 13% of the total. (The assumptions made here are that in both cases the blast is warmed from 100° to 750° C., *i.e.*, a heat input of 156 C.H.U. per lb. of air, that the Cowper stove wastes a further 39 C.H.U. per lb. of air, and that the work done in compressing the air is 21 C.H.U./lb. at the compressor shaft, or with 20% thermal efficiency at the turbine, 105 C.H.U. per lb. of air in terms of gas consumption). This is a very worthwhile saving, but what are the difficulties ? They rest in the manufacture, cost, and reliability of a metal-tube heat exchanger, using temperatures up to 750° C. on the blast air side and up to 900° C. on the gas side. A further difficulty associated with its employment with the bled axial compressor scheme is that the extra proportion of blast-furnace gas used with the air in the combustion chamber would lessen the demands of the gas turbine for air, and the bled axial compressor would become less flexible in its characteristics as viewed by the furnace. Furthermore, control difficulties are raised, since blast flows and blast heating are not inter-related. Essentially we must have independent control of gas-turbine inlet temperature and furnace air inlet temperature. The thermal inertia of the heat exchanger will involve a delay of minutes, and this could not be tolerated in the control of the gas turbine. The only solution would seem to be that the erstwhile stove operator must control the combustion-chamber temperature so as to secure, after the heat exchanger, the desired blast temperature. Meanwhile, the gas-turbine controls which formerly manipulated fuel controls must control by-pass air to dilute the heat-exchanger outlet gas to the desired temperature for the gas-turbine loading conditions.

Yet another approach to the blast heating problem is to take the blast air at a bleed from some intermediate point in the turbine expansion. With liquid and other high-calorific-value fuels the gas turbine normally has an exhaust oxygen content very little different to that of air. The situation is not quite so fortunate with blast-furnace gas because of its high nitrogen content, but setting aside the necessity for enriching the oxygen content it is instructive to consider such a case. Using the general assumptions adopted in the consideration of the previous suggestion to replace the Cowper stove with a heat exchanger, we may further assume that the blast air might be taken away from the turbine at 17 lb./sq. in. pressure and up to 450° C. The heat exchanger substituting for the stove need only raise the gas a further 300°–750° C. The exhaust gas might need enriching with ' cheap ' oxygen from turbo machinery if the blast-furnace reaction rates were to be maintained. Capital costs would obviously be high. Consideration also suggests that the blowing characteristics would be more flexible, but there would be little gain in overall efficiency.

Although the progress of development may show these speculations to be feasible in the practical sense, it would be unwise at this stage to encumber with these superficially attractive conjectures the bled-axial-compressor/gas-turbo-blower which promises to be a reasonably straightforward and useful development of the gas turbine.

Grateful acknowledgment is made to the Appleby-Frodingham Steel Co., Ltd., the Consett Iron Co., Ltd., and Messrs. Stewarts & Lloyds, Ltd., for helpful discussions with their staff on matters relating to blast-furnace control.

N E W S



ANNOUNCEMENTS AND NEWS OF SCIENCE AND INDUSTRY

THE IRON AND STEEL INSTITUTE
Meetings

PROTECTION OF IRON AND STEEL AGAINST CORROSION

A Meeting will be held at the offices of the Iron and Steel Institute on Thursday, 26th June, 1947, at 2.30 P.M., to discuss the following two papers issued under the auspices of the Protective Coatings Sub-Committee of the Corrosion Committee.*

"*The Effect of Different Methods of Pretreating Iron and Steel before Painting*" (Special Report No. 31), by F. Fancutt.

"*The Protection of Iron and Steel by Metallic Coatings*," by J. C. Hudson and T. A. Banfield.

The Chair will be taken by Mr. T. M. Herbert, Deputy Chairman of the Corrosion Committee and Chairman of the Protective Coatings Sub-Committee.

Persons who wish to attend the meeting are requested to notify the Secretary of the Iron and Steel Institute, who will be pleased to supply copies of the papers on request.

SYMPOSIUM ON POWDER METALLURGY

A meeting will be held in the afternoon of 18th June, and all day on 19th June, in the Lecture Theatre of the Institution of Civil Engineers, Great George Street, S.W.1, to discuss Special Report No. 38 (*see* notice below). A Buffet Luncheon will be held in the Library, Central Hall, Westminster, on 19th June, 1947.

The Council of the Iron and Steel Institute has issued, to members of the Institute of Metals, a cordial invitation to attend this meeting. A circular notice regarding the meeting will be sent out shortly to all members of the Iron and Steel Institute and of the Institute of Metals.

Invitations have also been sent to the Institution of Mechanical Engineers, the Institution of Electrical Engineers, the Institution of Production Engineers, the Institution of Automobile Engineers and the Society of Chemical Industry, asking them to inform their members of this meeting, and to say that any of them who wish to attend will be cordially welcome.

In the time available, it will not be possible to discuss each paper in Special Report No. 38 separately. Each section of the Report will, therefore, be discussed as a whole, a rapporteur briefly presenting the papers in each section before the subject is thrown open to discussion. It is hoped that authors of papers will speak in the discussion, and will reply, at the end of the discussion on each Section of the Report, to any important points raised. The following is the detailed programme :

Wednesday, 18th June

2.15 p.m. to 5.0 p.m.	**Afternoon Session in the Lecture Theatre of the Institution of Civil Engineers**
2.15 P.M.	Opening Address. Presentation and Discussion of Section A of Special Report No. 38, "*Powder Metallurgy in Great Britain*."
3 P.M.	Discussion on "*The Preparation, Properties and Testing of Metal Powders*," based on Section B of Special Report No. 38.
4 P.M.	Discussion on "*Magnetic Powders and Products*," based on Section C of Special Report No. 38.

Thursday, 19th June

10.0 a.m. to 12.45 p.m.	**Morning Session in the Lecture Theatre of the Institution of Civil Engineers**
10.00 A.M.	Discussion on "*Hard Metal Carbides*," based on Section C of Special Report No. 38.
11.30 A.M.	Discussion on "*Porous Metal Components*," based on Section E of Special Report No. 38.
12.45 p.m. to 2.00 p.m.	**Buffet Luncheon in the Library of Central Hall, Westminster**

* The Corrosion Committee was originally a Joint Committee of the Iron and Steel Institute and the British Iron and Steel Federation, and reported to the Iron and Steel Industrial Research Council, but was transferred to the care of the British Iron and Steel Research Association on 31st December, 1946.

2.15 p.m. to 5.00 p.m. Afternoon Session in the Lecture Theatre of the Institution of Civil Engineers

2.15 P.M. Discussion on "*The Manufacture and Properties of Sintered Ferrous Components*," based on Papers 18, 19, 20, 21, 22, 27 and 28 in Section F of Special Report No. 38.

3.45 P.M. Discussion on "*The Manufacture and Properties of Sintered Non-Ferrous Components*," based on papers 23, 24, 25, 26 and 27 in Section F of Special Report No. 38.

It is proposed to arrange a small Exhibition of Powder Metallurgy Products in connection with the meeting.

Tickets for the buffet luncheon on June 19th can be obtained from the Secretary of the Iron and Steel Institute, 4, Grosvenor Gardens, London, S.W.1, at the price of 6*s*. per ticket.

Members of the Iron and Steel Institute and of the Institute of Metals are asked to return the Reply Form, attached to the circular notice, as soon as they receive it, if they wish to attend the meeting and the buffet luncheon. Members of the other Institutions and Societies are asked to inform the Secretary of the Iron and Steel Institute if they wish to attend the meeting and the luncheon, and whether they wish to take part in the discussion on any of the Sections of Special Report No. 38.

Special Report No. 38

SYMPOSIUM ON POWDER METALLURGY

This Special Report, which is to be the subject of a meeting of the Institute on Wednesday, 18th and Thursday, 19th June, 1947, will be published by the Iron and Steel Institute at the end of May, 1947, and will be available, on demand, at a published price of 16*s*. per copy, and at a special reduced price of 10*s*. per copy to Members of the Iron and Steel Institute and of the Institute of Metals. Applications for copies of the Report, together with the necessary remittance, should be forwarded to the Secretary of the Iron and Steel Institute, 4, Grosvenor Gardens, London, S.W.1, as soon as possible.

Special Report No. 38 will be divided into six sections and will contain the following twenty-eight papers:

Section A: Introductory

1. "*Powder Metallurgy in Great Britain*," by W. D. Jones.

Section B: The Preparation, Properties, and Testing of Metal Powders

2. "*The Manufacture of Iron Powder by Electrodeposition*," by G. E. Gardam.
3. "*The Production of Ferrous and Non-Ferrous Metal Powders*," by G. L. Miller.
4. "*Some Properties of Engineering Iron Powders*," by L. Northcott, C. J. Leadbeater and F. Hargreaves.
5. "*Flake Metal Powders—Their Application, Manufacture, and Testing Methods*," by H. Meyersberg.

Section C: Magnetic Powders and Products

6. "*The Nature, Properties and Applications of Carbonyl-Iron Powders*," by L. B. Pfeil.
7. "*Comparison of Magnetic Powder Cores for High and Low Frequencies*," by G. R. Polgreen.
8. "*Nickel–Iron Alloys for the Production of Dust Cores*," by S. E. Buckley.
9. "*High Magnetic-Permeability Powder-Iron Components*," by D. A. Oliver.
10. "*The Production of Sintered Permanent Magnets*," by S. J. Garvin.

Section D: Hard Metal Carbides

11. "*The Preparation of Carbides*," by L. D. Brownlee, G. A. Geach, and T. Raine.
12. "*The Manipulation and Sintering of Hard Metals*," by H. Burden.
13. "*The Physical Metallurgy of Sintered Carbides*," by E. J. Sandford and M. Trent.
14. "*The German Hard-Metal Industry*," by G. J. Trapp, B. E. Berry, H. Burden, and T. Raine.

Section E: Porous Metal Components

15. "*The Structure of Porous Bronze Bearings*," by A. G. Metcalfe and A. Carter.
16. "*Highly Porous Metal Compacts with Special Reference to Filters*," by C. E. Sinclair.
17. "*De-Icing Equipment*," by T. K. S. (Aircraft De-Icing), Ltd.

Section F: The Manufacture and Properties of Sintered Components

18. "*The Properties of Certain Iron Powder Compacts*," by J. P. Burr and W. Clark.
19. "*Iron—Carbon Alloys by Powder Metallurgy*," by J. A. Judd.
20. "*Observations on the Pressing, Sintering, Heat-Treatment and Properties of Iron—Graphite Powder Mixtures*," by R. Chadwick and E. R. Broadfield.
21. "*Sintered Iron—Copper Compacts*," by L. Northcott and C. J. Leadbeater.
22. "*Observations on the Pressing, Sintering, and Properties of Iron—Copper Powder Mixtures*," by R. Chadwick, E. R. Broadfield, and S. F. Pugh.
23. "*A Note on the Powder Metallurgy Methods used in Great Britain for the Manufacture of Plain Bearings and Thrust Washers*," by W. H. Tait.
24. "*The Pressing and Sintering of Copper Powders*," by M. Cook and S. F. Pugh.
25. "*The Production of Some Non-Ferrous Engineering Components by Powder Metallurgy*," by J. W. Lennox.
26. "*Aluminium Components*," by R. L. Bickerdike.
27. "*Notes on German Developments in Non-Carbide Powder Metallurgy*," by C. J. Leadbeater.
28. "*German Sintered Iron Driving Bands*," by Lt.-Col. W. Ivory.

Staff Biography No. 5

Mr. Eric R. Mort, Managing Editor, was born in 1908; he was educated at Wellington School and University College, Swansea, where he took a B.Sc. degree in metallurgy.

In 1928 Mr. Mort joined Messrs. Baldwins Ltd., as Works Metallurgist to their Panteg Sheet Works, Monmouthshire Division, and two years later presented a paper to the Iron and Steel Institute on "*Sheet and Tin-Mill Rolls—their Treatment, Performance and Premature Failure in Service.*"

In the autumn of 1930 he went to the U.S.A., where he became a metallurgist in the Research Department of the Inland Steel Company's Indiana Harbor Works. In 1932, he transferred to that Company's newly erected strip-sheet mill and, later, undertook an extensive tour of strip mill installations before returning to England.

Some of the results of Mr. Mort's American experience were embodied in a paper entitled "*The Manufacture of Full-Finished Steel Sheets*," presented to the Iron and Steel Institute in 1934. In that year he became Assistant Editor of *Iron and Steel* and *Metal Industry* but left to become Chief Metallurgist of the Kelsey-Hayes Wheel Co., Ltd., in 1935. He returned later to technical journalism and became Editor of *Metal Industry* in 1937.

In 1941 Mr. Mort joined the Ministry of Supply, and became Assistant Superintendent of Tank Design, in charge of the development of cast armour. He was a member of the British Armour Mission which visited U.S.A. in 1942 to study American practice in the manufacture of armour and its application to fighting vehicles. In 1943 he was released to join Messrs. Sanderson Bros. and Newbould Ltd., Sheffield, and was later appointed Technical Manager. He resigned in August last to accept the appointment of Managing Editor of the Institute's publications.

Mr. Mort was elected an Associate Member of the Iron and Steel Institute in 1930, transferring to Membership in 1933. He became a Member of the Institute of Metals in 1938 and was elected a Fellow of the Institution of Metallurgists in 1946.

NEWS OF MEMBERS

Recent Appointments

▸ Mr. W. H. GREAVES has joined the Department of Research and Technical Development at Messrs. Stewarts and Lloyds, Ltd., Bilston.

▸ Mr. D. RIST has left the Redcar Works of Messrs. Dorman, Long & Co. Ltd., to join the Blast Furnace Department of the Clyde Ironworks of Messrs. Colvilles, Ltd.

▸ Mr. I. C. HERBERT is leaving South Wales to take up an appointment with the Rhokana Corporation, Ltd., Northern Rhodesia.

▸ Mr. J. G. LESCHEN has joined the staff of the Research Laboratories of the General Electric Co., Schenectady, N.Y., U.S.A.

▸ Mr. S. W. RAWSON has been elected to the Board of Messrs. A. C. Wickman, Ltd., and has been appointed a Member of the Gauge and Tool Advisory Council.

▸ Mr. A. L. FEILD has been appointed Associate Director of the laboratories of the American Rolling Mill Co., Middletown, Ohio., U.S.A.

▸ Dr. G. S. FARNHAM has been appointed metallurgist with the International Nickel Company of Canada, Ltd.

▸ Mr. E. J. EVANS is leaving the staff of Magnesium Elektron, Ltd., to take up an appointment as assistant metallurgist at the Newport Works of Messrs. Stewarts and Lloyds, Ltd.

▸ Dr. T. A. BANFIELD is joining the staff of the British Anti-Fouling Composition and Paint Co., Ltd., as a research chemist.

▸ Mr. G. H. LATHAM has been appointed President of the British Iron and Steel Research Association in succession to Sir James Lithgow.

▸ Mr. E. W. COLBECK will be leaving Imperial Chemical Industries, Ltd., to become a Director of Hadfields, Ltd., on 1st July.

▸ Mr. F. L. SMITH has been appointed Chief Technical Engineer in charge of the Central Engineering Department of Messrs. Dorman, Long & Co., Ltd.

▸ Dr. J. T. MACKENZIE has joined the Board of Directors of the American Cast Iron Pipe Co., Birmingham, Ala., U.S.A.

▸ Mr. T. J. L. THOMSON has left the Darlington and Simpson Rolling Mills, Ltd., to become General Manager of Messrs. Bruntons (Musselburgh), Ltd.

▸ Mr. T. B. WILKINSON has become Metallurgist with the Research Department, English Electric Company, Ltd., Stafford. He was previously Lecturer in Metallurgy, at University College, Swansea.

▸ Mr. E. H. FORS, who was reported in the March issue of the *Journal* as having left the Morgan Construction Company, has joined the Davy and United Engineering Co., Ltd., as liaison officer

and still remains in the service of the Morgan Construction Company.

Elections

▸ Dr. A. McCance has been elected a Vice-President of the Institution of Engineers and Shipbuilders in Scotland.

▸ Lord Dudley Gordon has been elected President of the Institution of Mechanical Engineers.

▸ Mr. K. Headlam-Morley has been elected a Vice-President of the Ebbw Vale Metallurgical Society.

Awards

The President and Members of Council offer their congratulations to :

▸ Mr. R. J. Allen, who is to be awarded the Meritorious Service Gold Medal of the American Foundrymen's Association.

▸ Col. N. T. Belaiew, who has been awarded the Diploma of " Officier d'Academie " of the Ministry of Education.

Obituary

The Council regret to record the death of :

M. Maurice Derclaye.

Mr. John P. O. Dutton, Director of Messrs. Fergusson, Wild & Co., Ltd.

IRON AND STEEL ENGINEERS GROUP

The **Fourth Meeting** of the Iron and Steel Engineers Group will be held at 4, Grosvenor Gardens, London, S.W.1, on Wednesday, 11th June, 1947.

At the morning session, from 10.30 a.m. to 12.45 p.m., Mr. I. V. Robinson will present a paper on " *Steam Turbines for Iron and Steel Works,*" and Mr. A. S. Peacock will present a paper on " *Water-Tube Boilers for Iron and Steel Works,*" submitted by the Water-Tube Boilermakers' Association.

After a Buffet Luncheon, the afternoon session, from 2.0 p.m. to 4.15 p.m., will be devoted to the discussion of a paper on " *Gas Turbine Applications in Iron and Steel Works,*" presented by Dr. A. T. Bowden, Mr. W. H. Gibson, Mr. J. W. Railly and Mr. R. G. Voysey.

The papers for discussion at the meeting are published on pages 81 to 118 of this issue.

THE BRITISH IRON AND STEEL RESEARCH ASSOCIATION

Refresher Course on Steelmaking

The Fourth Refresher Course on Steelmaking, arranged by the Steelmaking Division of the Association, is to be held at the Royal Technical College, Glasgow, during the week commencing Monday, 30th June, 1947.

With a series of morning lectures, followed by tutorial instruction and discussion during the afternoons, the course will deal with a study of equilibrium systems, of fundamental interest to steelworks technicians, special attention being devoted to complex systems. A visit to a steelworks will be arranged for the afternoon of Wednesday, 2nd July.

Further detailed particulars of the course may be obtained on application to the Technical Secretary, Steelmaking Division, the British Iron and Steel Research Association, 11, Park Lane, London, W.1.

Library and Information Services

The Iron and Steel Institute and the British Iron and Steel Research Association have agreed that the following principles shall determine the preparation and dissemination of Technical Information :

1. The Library at the Iron and Steel Institute shall be the main Reference Library for all the combined services. Every effort shall be made that it shall remain complete, comprehensive and covering the extended requirements of the Research Association.

2. The Iron and Steel Institute shall be responsible for Bibliographies, Abstracts, Translations and other extractions of information from published sources.

3. Matters calling for a specialized technical appreciation, such as balanced reviews, deductions or suggestions in the nature of development shall be dealt with by the Research Association.

4. Information arising from current programmes of research and other unpublished information shall be dealt with by the Research Association.

5. Information required by Member Companies of the British Iron and Steel Research Association and beyond the agreed scope of the Iron and Steel Institute Library shall be obtained from other libraries by the staff of the British Iron and Steel Research Association.

6. Normally enquiries from Members of the Iron and Steel Institute should be put to the Institute and enquiries from Member Companies of British Iron and Steel Research Association to the Research Association. Actual preparation of the information required shall be according to clauses (2), (3), (4) and (5) above.

INSTITUTION OF METALLURGISTS

Examinations

Examinations for the Licentiateship and Associateship of the Institution of Metallurgists will be held during the week commencing 8th September, 1947, in London and other centres to

be decided upon when the number of candidates in different areas is known.

Application for permission to enter for the examination should be made not later than 14th June, 1947, on forms to be obtained, with copies of the regulations, from the Registrar, the Institution of Metallurgists, 4, Grosvenor Gardens, London, S.W.1.

Full details of the arrangements for the examinations, and instructions as to payment of fees, will be sent to those whose applications are accepted.

The attention of intending candidates is drawn to the following regulations which must be complied with, before permission to enter for the examinations can be given :

Each candidate for the Institution's examination for the Licentiateship must produce evidence of :

(*a*) Good general education.

(*b*) Knowledge of chemistry, physics, and mathematics to approximately university intermediate science examination standard.

(*c*) Not less than two years' experience in metallurgical science or practice.

Each candidate for the Institution's examination for the Associateship must produce evidence of :

(*a*) General education to approximately matriculation standard.

(*b*) Knowledge of chemistry, physics and mathematics to approximately university intermediate science examination standard.

(*c*) Three years' experience in metallurgical science or practice.

Examinations for the Fellowship may be arranged at about the same date, and intending candidates should apply for permission to enter for the examination stating the branch of metallurgy in which they wish to be examined.

Examination Fees :

Licentiateship Examination ...	£3	3	0
Associateship Examination :			
Licentiates	£3	3	0
Other Candidates	£5	5	0
Fellowship Examination :			
Associates	£5	5	0
Other Candidates	£10	10	0

MOND NICKEL FELLOWSHIPS

In February 1946, Sir William Griffiths, D.Sc., Chairman and Managing Director of The Mond Nickel Company, Limited, addressed a letter to the Presidents of the Institute of Metals, the Iron and Steel Institute, the Institution of Mining and Metallurgy, the Institute of British Foundrymen, and the Institution of Metallurgists, inviting them to co-operate with The Mond Nickel Company, Limited in awarding annually, for the next fifteen years, a number of Fellowships, to be known as "Mond Nickel Fellowships." The Mond Nickel Company, Limited offered to make available over a number of years, the sum of £50,000 to be used for awarding these Fellowships. The five Institutes and Institutions accepted with pleasure the offer made by the Company and agreed to co-operate in awarding and administering the Fellowships.

Mond Nickel Fellowships will be awarded to persons of British nationality, educated to University degree or similar standard, though they need not necessarily be qualified in Metallurgy. There are no age limits, though awards will seldom be made to persons over 35 years of age. Each Fellowship will occupy one full working year. It is proposed to award up to five Fellowships each year, of an average value of £750.

Mond Nickel Fellowships will be awarded with the following objects :

(*a*) To allow selected persons to pursue such training as will make them better capable of applying the results of research to the problems and processes of the British metallurgical and metal-using industries.

(*b*) To increase the number of persons who, if they are subsequently employed in executive and administrative positions in the British metallurgical and metal-using industries, will be competent to appreciate the technological significance of research and its results.

(*c*) To assist persons with qualifications in metallurgy to obtain additional training, helpful in enabling them ultimately to assume executive and administrative positions, in British metallurgical and metal-using industries.

(*d*) To provide training facilities whereby persons, qualified in sciences other than metallurgy, may be attracted into the metallurgical field and may help to alleviate the shortage of qualified metallurgists available to industry.

They will be awarded to selected candidates who wish to undergo a programme of training in industrial establishments and will normally take the form of travelling Fellowships : awards for training at Universities may, however, be made in special circumstances.

Applicants will be required to state the programme of training in furtherance of which they are applying for an award, as well as particulars of their education, qualifications and previous career.

Full particulars and the necessary forms of application can be obtained from the Secretary, Mond Nickel Fellowships Committee, 4, Grosvenor Gardens, London, S.W.1. Completed application forms will be required to reach the Secretary of the Committee not later than 1st September, 1947.

EDUCATION

The University of Birmingham Open Scholarships in Metallurgy

Six scholarships of the annual value of £50, tenable for three years in the Department of Metallurgy, will be awarded in 1947. They are particularly intended for young men in Industry who might wish to complete their education at Birmingham University.

These scholarships are eligible for supplementation by the Ministry of Education, and the Ministry is prepared to add a maintenance allowance in each case, based on a means test.

Applicants must have complied with the requirements of the Joint Matriculation Board for entry upon a degree course and they should possess the Higher School Certificate of a recognized examining body, or be candidates for such certificates, in the year in which they are candidates for the scholarship. Alternatively, candidates may possess the Intermediate B.Sc. of the University of London, or be candidates for the examination in the year of the award of the scholarship. Candidates for the scholarship must present, or have presented, Chemistry, Physics, and Mathematics at the Higher School Certificate Examination or London Intermediate Examination, two at least of these subjects being at principal or group standard.

A Metallurgy Scholarship cannot also be held with a State Scholarship or any similar award of comparable value, or by a student in the Education Department under the regulations for the Training of Teachers. The continuance of the scholarship will be subject to satisfactory reports on the scholar's work and conduct.

Applications for the scholarships, which are restricted to candidates of British nationality born not earlier than 1st January, 1922, should be forwarded to the Registrar of the University of Birmingham not later than 30th June, 1947. (A form of application and syllabus of the Faculty of Science can be obtained from the Registrar.) Final acceptance of each candidate is subject to the approval of the Joint Recruiting Board.

The University course commences in October, 1947.

ANDREW CARNEGIE RESEARCH FUND

Travelling Scholarships

The Council of the Iron and Steel Institute announce that they are prepared to award one or two Andrew Carnegie Travelling Scholarships each year. The value of the Scholarships will depend on the circumstances of each case. They will normally be of the order of £500, but smaller or substantially greater sums may be given. The Scholarships will usually be tenable for one year and are intended to assist recipients to conduct research outside the United Kingdom.

Research Grants

Awards will also be made of Carnegie Research Grants tenable in the United Kingdom. The amount of any one grant will not exceed £250 in a year and the normal range is from £50 to £200.

Conditions

A condition of these awards is that candidates must be under 35 years of age. There is no restriction on sex or nationality.

The Carnegie Scholarships and Grants are intended to enable investigators to conduct researches into the metallurgy of iron and steel. The scheme is not intended to facilitate ordinary collegiate studies, but proposals for post-graduate research and work for higher degrees, as well as applications for grants in aid of investigations at works will be considered. The Council are prepared to take a wide view of the terms of reference.

The results of the research are to be communicated to the Iron and Steel Institute in the form of a Report for publication. An Andrew Carnegie Gold or Silver Medal may be awarded to the author of the Report which, in the opinion of the Council, is the most meritorious of the year.

Grants will normally be paid in four quarterly instalments ; the first on award, the second and third on receipt of satisfactory brief progress reports, and the final instalment on receipt of the completed report.

Applications

Applications should be made on the appropriate form (obtainable on application to the Secretary of the Institute) not later than **7th June, 1947**.

CONTRIBUTORS TO THE JOURNAL

H. Escher—Combustion Engineer at Australian Iron and Steel, Ltd. Mr. Escher was born in Cairo and received his technical education in Switzerland, at Zurich and Winterthur, where he graduated in Mechanical Engineering in 1926.

Mr. Escher was first employed by Escher Wyss et Cie., in their turbine research department. In 1927 he went to Australia, during the construction of the new steelworks plant at Port Kembla, and joined the staff of Australian Iron and Steel, Ltd., where he carried out design work, construction and testing. He was appointed Combustion

Engineer in 1933, and since then he has been responsible for directing the various phases of fuel utilization and associated problems. In 1939 he was awarded the Ablett prize by the Council of the Iron and Steel Institute for his paper entitled "*Ten Years' Development in Steam Engineering at the Port Kembla Steelworks, N.S.W., Australia.*"

F. W. Jones, B.Sc., Ph.D.—Member of the staff of the Physics Department, Brown-Firth Research Laboratories, Sheffield. Mr. Jones was educated at Sheffield and Manchester Universities, and from 1934 to 1941 carried out work on the order/disorder transformation, particle size measurement by X-rays, and age-hardening, at Messrs. Metropolitan-Vickers Electrical Co., Ltd., Manchester. He joined the staff of the National Physical Laboratory, Metallurgy Division, in 1941, where he carried out work on armour-piercing shot in co-operation with the Terminal Ballistics Branch of Armament Research Department. He took up his present appointment in July 1946.

W. I. Pumphrey, M.Sc.—Leader of the Aluminium Welding Research Team of the Aluminium Development Association at Birmingham University. Mr. Pumphrey was educated at King's School, Chester, and at Birmingham University, where he graduated in 1942. He joined the staff of the Metallurgy Division, National Physical Laboratory in the same year, obtaining his M.Sc. at Birmingham University in 1944, where his work consisted mainly of research on the hardenability and transformation characteristics of high carbon steels and binary ferrites. In 1946 Mr. Pumphrey joined the Aluminium Development Association.

Martin L. Hughes, M.Sc., F.I.C.—Head of Metallurgy Section, Swansea Laboratories, British Iron and Steel Research Association. Mr. Hughes was born in 1900 and was educated at Llanelly County School and at Swansea Technical College. He joined the Llanelly Steel Co., Ltd., where he served in various capacities for twenty years. In 1935 he obtained the degree of B.Sc. of London University, with Second Class Honours, and was appointed part-time lecturer at Swansea Technical College, becoming Responsible Lecturer in Metallurgy in 1937. In 1941 Mr. Hughes undertook research work at University College, Swansea, for the South Wales Siemens Steel Association, and the Welsh Plate and Sheet Manufacturers' Research Association ; he left, in 1946, to join the British Iron and Steel Research Association. Mr. Hughes is a Member of Council of the Swansea and District Metallurgical Society.

J. H. Oldfield—Member of the staff of the Royal Naval Scientific Service and in charge of the research and development section of the Bragg Laboratory, Naval Ordnance Inspection Department, Sheffield. Mr. Oldfield joined the staff of the metallurgical and chemical inspection laboratories of the Admiralty in Sheffield, in 1926, after a short spell in industry, and in 1935 was transferred to the newly formed spectrographic section there. He has been associated with industrial spectroscopy continuously since then, and his early problems concerned the development of spectrographic methods for the routine analysis of the various types of ferrous and non-ferrous alloys with which the Admiralty laboratory had to deal.

During his career he has been responsible for the training of a number of industrial spectroscopists, and has lectured and presented papers to technical societies.

Mr. Oldfield is a member of a number of spectroscopic bodies, including the Committee of the Industrial Spectroscopic Group of the Institute of Physics and Spectrographic Sub-committee of the British Iron and Steel Research Association.

T. Land—Director of T. Land & Son, Ltd., Sheffield. A biographical note on Mr. Land appeared on page 625 of the April issue of the *Journal*. A recent portrait is given below.

H. Escher

W. I. Pumphrey

T. Land

CAMBRIDGE SUMMER SCHOOL IN METAL PHYSICS, 1947

By the courtesy of Professor Sir Lawrence Bragg, O.B.E., F.R.S., a Summer School in Metal Physics will be held this year in the Cavendish Laboratory, University of Cambridge.

The School will provide an introduction to the application of physical methods to the examination and utilization of metals, and is intended for those whose researches require a more fundamentally physical approach than is usual in ordinary metallurgical and engineering practice. The lectures and demonstrations will deal with (*a*) Application of X-ray methods in the examination of metals, (*b*) Physical and mechanical properties of metals. Both parts (*a*) and (*b*) will be taken by all attending the School, and for part (*a*) an elementary knowledge of X-ray diffraction methods and of crystal symmetry will be assumed; during the School it will be possible to provide only a very brief review of these aspects of the subject-matter.

The School will be held from Monday, 1st September to Friday, 12th September inclusive. A detailed syllabus and form of application for admission may be obtained from G. F. Hickson, M.A., Secretary of the Board of Extra-mural Studies, Stuart House, Cambridge, to whom the completed application form should be returned not later than 7th June, 1947.

The Summer School in X-ray Crystallography, held in Cambridge in recent years, will **not** be held in Cambridge this year.

TRANSLATION SERVICE

Since the announcement made in the April issue of the *Journal* (*see* page 626, Volume 155), further translations have been put in hand and the following are now available or in course of preparation.

TRANSLATION AVAILABLE

No. 307 (Swedish). B. D. ENLUND: "Recent Swedish Investigations on the Ageing of Steel" (*Jernkontorets Annaler*, 1946, vol. 130, No. 10, pp. 553–573).

TRANSLATIONS IN COURSE OF PREPARATION

(Swedish). C. G. CARLSON and R. RYNNINGER: "Electric Apparatus for Light Emission in Spectrum Analysis." (*Jernkontorets Annaler*, 1947, vol. 131, No. 1, pp. 1–25). (Translation provided through the courtesy of the authors).

(German). E. COTEL: "The Development of the Blast-Furnace Profile." (*Royal Hungarian Palatine Joseph University, Publication of the Department of Mining and Metallurgy*, 1941, vol. 13, pp. 3–10).

(German). A. GELEJI: "Power Requirements for Rolling and for Mill Trains." (*Royal Hungarian Palatine Joseph University, Publication of the Department of Mining and Metallurgy*, 1940, vol. 12, pp. 192–212).

(German). A. GELEJI: "The Theoretical Problems Involved in the Design of Rolling-Mill Stands." (*Royal Hungarian Palatine Joseph University, Publication of the Department of Mining and Metallurgy*, 1941, vol. 13, pp. 224–242).

(German). A. GELEJI: "Calculating the Forces Arising and the Power Requirements in the Mannesmann Tube-Rolling Process." (*Royal Hungarian Palatine Joseph University, Publication of the Department of Mining and Metallurgy*, 1941, vol. 13, pp. 208–223).

(Russian). S. HERZRÜCKEN and M. FEINGOLD: "The Calculation of the Diffusion Coefficient in Mixtures of Powdered Substances." (*Journal of Technical Physics* (*U.S.S.R.*), 1940, vol. 10, No. 7, pp. 574–577).

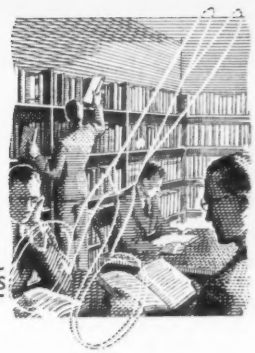
(German). F. KÖRBER and W. OELSEN: "The Action of Carbon as a Reducing Agent in the Reactions of the Steelmaking Processes with Acid Slags." *Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung*, 1935, vol. 17, No. 4, pp. 39–61).

(Russian). M. A. SHAPOVALOV: "Performance of a Blast-Furnace with Oxygen-Enriched Blast." (*Kislorod*, 1944, No. 1, pp. 17–31).

CHARGES FOR COPIES OF TRANSLATIONS.—For the above translations a charge will be made of 10*s*. for the first copy and 5*s*. for each additional copy of the same translation. Requests for translations should be accompanied by a remittance. The above translations are not available on loan from the Joint Library.

TRANSLATIONS PREPARED AT MEMBERS' REQUEST. — Members requiring translations of foreign technical papers are invited to communicate with the Secretary, who will ascertain whether the translations can be prepared for inclusion in the series.

ABSTRACTS OF CURRENT LITERATURE *and* BOOK NOTICES



IRON AND STEEL MANUFACTURE AND RELATED SUBJECTS

CONTENTS

	PAGE
ORES—MINING AND TREATMENT	127
FUEL—PREPARATION, PROPERTIES, AND USES	128
REFRACTORY MATERIALS	129
BLAST-FURNACE PRACTICE AND THE PRODUCTION OF PIG IRON	131
PRODUCTION OF STEEL	132
HEATING FURNACES AND SOAKING PITS	133
FORGING, STAMPING, DRAWING, AND PRESSING	134
MACHINERY FOR IRON AND STEEL PLANT	135
LUBRICANTS AND LUBRICATION	136
MACHINING AND MACHINABILITY	136
CLEANING AND PICKLING	137
PROTECTIVE COATINGS	138
PROPERTIES AND TESTS	139
METALLOGRAPHY	141
INDUSTRIAL USES AND APPLICATIONS	142
HISTORICAL	142
ECONOMICS AND STATISTICS	142
MISCELLANEOUS	143
BOOK NOTICES	143
NEW PUBLICATIONS	144

ORES—MINING AND TREATMENT

Significant Factors in Dust Control at Some Iron-Ore Mines of the Lake Superior District. E. C. J. Urban. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2087 : Mining Technology, 1947, vol. 11, Jan.). Methods developed in iron-ore mines of the Lake Superior district to reduce dust and the danger of silicosis when drilling ore and rock are reviewed.—R. A. R.

The Problem of Mineral Dusts in Swedish Mining. E. Wesslau. (Jernkontorets Annaler, 1947, vol. 131, No. 2, pp. 29–30). (In Swedish). In 1942 Jernkontoret appointed a committee to study the dust problem in Swedish mining. This short paper serves as an introduction to the three reports on the committee's work, abstracts of which follow.—R. A. R.

Silicosis. J. Pontén. (Jernkontorets Annaler, 1947, vol. 131, No. 2, pp. 31–39). (In Swedish). This paper, by the medical member of the Jernkontoret Committee on Silicosis, gives a short historical outline of the knowledge of silicosis and its effects, and describes medical and other measures of prevention.—R. A. R.

Silicosis in Swedish Ore Mines. T. Fahlman. (Jernkontorets Annaler, 1947, vol. 131, No. 2, pp. 40–49). (In Swedish). The results of an analysis of the incidence of silicosis in Swedish mines are reported and Swedish regulations regarding the medical examination of men exposed to the risk of silicosis are reviewed. Technical measures for preventing the spread of dust are considered.—R. A. R.

Investigations of Methods of Binding the Dust in Mines and Crushing Plants. T. Löfgren. (Jernkontorets Annaler, 1947, vol. 131, No. 2, pp. 50–60). (In Swedish). A series of dust determinations was made under different conditions after shot-firing in mines, and the spread of the dust was studied with and without the use of curtains of spray. A spray nozzle was designed which required about 0·4 cu. m. of air/min. In certain cases it was possible to apply the spray to precipitate the dust on the area of origin and thus prevent it from spreading over large areas in the mine. Dust determinations during scraper-loading underground indicated that the silicosis risk was small. Dust tests at a crushing plant were also made and measures which resulted in a considerable reduction in the dust concentration are described.—R. A. R.

Mineral-Dressing Characteristics of the Red Iron Ores of Birmingham, Ala. W. H. Coghill and G. D. Coe. (United States Bureau of Mines, 1946, Bulletin No. 464). This paper deals with the geography, geology, mining, milling, concentration, and smelting of the Red Mountain iron ores at Birmingham, Alabama, with special reference to beneficiation tests by the Federal Bureau of Mines.—R. A. R.

A New Method of Beneficiation of Low Grade Iron Ore by the Wiedelmann Washing Tower. (British Intelligence Objectives Sub-Committee, July, 1946, F.I.A.T. Final Report No. 869 : H.M. Stationery Office). A description

is given of the concentration of low-grade iron ore by means of a washing tower developed by Wiedelmann of Ilsederhütte. The ore, crushed in rolls to — 50 mm., is fed into the top of the tower, which has a hopper-bottom. During continual washing by air and water, the clay tends to separate from the ore, and is carried off in the overflow as a fine suspension. The heavier ore tends to collect at the bottom of the tower, whence it is discharged by an air-lift on to a horizontal cylindrical screen for further washing. Tests show a recovery of 91·55% of the iron, with an increase in iron concentration from 21·61% in the raw ore up to 38·88% in the dried, washed, product.—C. O.

The Renn-Wälz Process. M. Tettenborn. (Technik, 1946, vol. 1, Dec., pp. 276–279). Waste materials containing considerable amounts of iron and other metals are produced in the smelting of zinc and lead ores. This material cannot be treated in blast-furnaces because of the presence of other volatile and non-volatile metals, but it can be worked up in long rotary kilns by the Renn-Wälz process, a description of which is given. The material is brought up to 1000° C. in the preheating zone of the kiln by the countercurrent gases, and this drives off CO_2 from the carbonates. The process then differs from the Krupp-Renn method in that it is a volatilization process for recovering molten metals in oxide form. The metal vapours are oxidized by excess air and carried off in the flue gases from which they are subsequently filtered. The non-volatile metals iron and copper behave similarly; about 10% of each passes into the slag and 6–8% passes as dust into the gases, so that 80–85% of these metals is in the pasty product of the kilns. If silver is present about 8% is lost in the slag and 15% passes into the gases. Whether the iron-rich product can be used in the blast-furnace depends upon the amounts of sulphur and arsenic in the raw material. —R. A. R.

The Technique and Application of the Krupp-Renn Process. K. Blume. (Technik, 1946, vol. 1, Dec., pp. 271–275). The Krupp-Renn rotary-kiln process of concentrating iron ores is described in detail and its advantages for the concentration of German siliceous ores are pointed out. Tables with operating data on the production of steel in electric-arc and open-hearth furnaces with charges containing from 20% to 100% of this concentrate are given. The process has proved to be of great commercial value and several plants have been erected in Europe as well as in Japan and Manchuria.—R. A. R.

Krupp-Renn and Other Processes for Utilizing Low-Grade Iron Ores in Germany. (British Intelligence Objectives Sub-Committee, 1946, F.I.A.T. Final Report No. 799: H.M. Stationery Office). An account is given of the history of the reduction of iron ores by means other than blast-furnace smelting. Methods of dressing low-grade German ores are discussed, with particular reference to the costs and operation of the Krupp-Renn and Lurgi processes. A brief reference is made to the application of the Krupp-Renn process to the production of ferronickel and non-ferrous metals.—C. O.

FUEL—PREPARATION, PROPERTIES, AND USES

The Action of Oxygen on Coal at Moderate Temperatures. W. J. Kramers. (Monthly Bulletin of the British Coal Utilisation Research Association, 1946, vol. 10, Dec., pp. 395–404). This is a review of previous work on the direct action of oxygen on coal at temperatures up to the ignition point. A list of 38 references to the literature on the subject is appended.—R. E.

Simplified Calculations of the Volume and Heat Content of Flue Gases. (Engineering and Boiler House Review, 1946, vol. 61, Nov., pp. 145–146, 153). Six charts are presented in which all the data required for the calculation of air and gas volumes and heat contents of flue gases are expressed in terms of the gross calorific value of the coal being burned, the percentage by volume of carbon dioxide in the flue gas, and the temperature of the air or gas. An example is given of the type of problem which can rapidly be solved by the use of the charts, *i.e.*, the chimney heat loss of a boiler using bituminous coal.—C. O.

Oil Firing for Industrial Boilers. (Engineering and Boiler House Review, 1947, vol. 62, Mar., pp. 80–85). The technique of fuel-oil firing is discussed, with special reference to conversion from coal to fuel-oil firing. Specifications are given of Pool fuel oil and Pool heavy fuel oil, and the terms specific gravity, Baumé scale, flash point, viscosity, and pour point, are explained. The essential requirements of a fuel-oil-burning plant are outlined and details are given of rotary, steam-jet, air-jet, and mechanical pressure atomizing burners.—G. C. J.

Where Do Gas-Oil Burners Fit in? O. Lutherer. (Industrial Heating, 1946, vol. 13, Dec., pp. 1959–1968, 1988). The limitations and advantages of burners which may be adapted to the use of both gas and oil, either separately or simultaneously, are discussed. Such burners find their main application in furnaces operating at above 800° F., with large combustion chambers, and when the presence of sulphur in the flue gases and oil fumes and smoke in the atmosphere are not deleterious. —C. O.

The "Parsons" Gas Turbine. (Steam Engineer, 1946, vol. 16, Dec., pp. 91–94). A general description is given of the new gas turbine developed by Messrs. C. A. Parsons and Co., Ltd., at their Heaton Works, Newcastle-on-Tyne. The turbine is intended for stationary installation; the fuel used is "Pool" fuel oil.—C. O.

The Installation and Operation of a Fuel Control Centre in an Integrated Iron and Steel Works. A. W. Lee. (Lincolnshire Iron and Steel Institute, 1946, Dec. 17). The installation and operation of a fuel-control centre in an integrated iron and steel works in the North Lincolnshire district are described.—J. R.

The Calculation of Variable Heat Flow in Solids. N. R. Eyres, D. R. Hartree, J. Ingham, R. Jackson, R. J. Sarjant, and J. B. Wagstaff. (Philosophical Transactions of the Royal Society, 1946, Series A, vol. 240, Aug. 2, pp. 1–57). The primary purpose of the work described was the development of a practical method of evaluating solutions of the equations of heat conduction in solids, under non-steady conditions, which should be free from the restriction to constancy of thermal properties.

The paper is in four parts. Part I is concerned with the basic approximation by which the partial differential equation of heat conduction is reduced to a set of ordinary differential equations, and with the results obtained by using this approximation in the various forms of the heat-conduction equation appropriate to bodies of different shapes and with different degrees of symmetry in the heat flow. Part II presents some results of calculations of variable heat flow in materials of which the thermal properties are independent of temperature, while Part III deals with the general case of heat conduction in a material the thermal properties of which vary with temperature. Part IV treats of an ingot cooling in the mould, where the heat flow occurs by conduction through the material of the ingot and the mould, and by radiation across the gap between them. An Appendix gives analytical solutions of the equations of one-dimensional heat flow for constant diffusivity. This paper

is " the other paper " referred to by the authors in their earlier communication entitled " Variable Heat Flow in Steel," published in Journ. I. and S.I., 1944, No. II, pp. 211P–267P.—A. E. C.

Heat Transfer from a Vertical Plate to an Air Stream. L. Slegel and G. A. Hawkins. (Purdue University, Engineering Experiment Station, Research Series No. 97 : Engineering Bulletin, 1946, vol. 30, May). Tests were carried out to determine the heat-transfer coefficients for a heated vertical plate, $\frac{1}{8}$-in. thick, in an air stream flowing parallel to the plate surface at velocities of 32 to 66 ft./sec., the temperature difference ranging from 22° F. to 229° F. Results could be expressed by the equation $Nu = 0{\cdot}0492\ (Pe)^{0{\cdot}8}$ where Nu and Pe refer to the Nusselt and Peclet numbers respectively.—M. A. V.

Cooling and Heating Rates of Plates, Cylinders and Spheres. V. Paschkis. (Welding Journal, 1946, vol. 25, Sept., pp. 497-s–502-s). A series of charts is presented which enable the heating and cooling rates at the centre, at points midway between the centre and the surface, and at the surface, of cylinders, plates, and spheres to be calculated. The construction of the curves is explained in an appendix.—C. O.

The Inorganic Constituents of Coal. H. E. Crossley. (Institute of Fuel Bulletin, 1946, Dec., pp. 57–60, 67). The inorganic minerals associated with coal may be classified in the three main groups—shales or clays, sulphides, and carbonates. The mode of occurrence of these minerals in coal and their industrial significance are discussed.—C. O.

Distribution of Ash in British Coals and Its Bearing on the Economics of Coal Cleaning. E. S. Grummell and A. C. Cunningham. (Institute of Fuel Bulletin, 1946, Dec., pp. 45–56). The relationship between the ash content and the specific gravity of coal is discussed, and the terms clean coal, middlings, and refuse or dirt are defined. Data are presented on the ash content of British coal and its regional variations, and on the economics of cleaning coal down to various ash contents. The thermal and economic losses incurred in cleaning coal are considerable and may increase the cost to the consumer, besides wasting valuable national assets, particularly as the seams of better coal become exhausted. —C. O.

Some Novel Methods of Coal Pulverization. (Engineering and Boiler House Review, 1946, vol. 61, Nov., pp. 147–153). Two methods for pulverizing coal without the use of moving metallic parts are described and illustrated. In the first, coarsely crushed coal is entrained in a rapidly moving stream of air or gas and discharged through a suitable orifice against a wear-resisting metallic baffle-plate, the impact causing disintegration. Mills of this type have been installed in Russia and Germany. The second method produces an intimate mixture of superheated steam and pulverized coal by an " explosion " process. The coal is subjected to a very high pressure in steam, and then the steam is released as rapidly as possible through a nozzle. Investigations on this process carried out by J. T. Yellott and A. D. Singh with a view to its employment in coal-fired gas-turbine locomotives are reviewed.—C. O.

Enameled Screen Gives Best Results in Screening Coke Breeze and Damp Materials. F. J. Geyer. (Blast Furnace and Steel Plant, 1946, vol. 34, Dec., pp. 1529–1530). An account is given of the marked increase in the life of wire-cloths used in screening coke fines which was obtained by coating the wires with vitreous enamel at 450° F.—C. O.

Metallgesellschaft A.G. and Lurgi Bau, Frankfurt am Main. Electrostatic Separation of Coal and Other Minerals. (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 1035 : H.M. Stationery Office).

Report on Solid Fuels. (British Intelligence Objectives Sub-Committee, 1947, J.I.O.A., Report No. 35 : H.M. Stationery Office). The information obtained during an investigation into the mining and utilization of coal in Western Germany is presented and discussed in relation to modern American practice. Among the individual installations referred to are a plant recovering methane from an abandoned coal mine, a unit for briquetting coal without a binder, and several high-temperature coking plants.—C. O.

Trends in Coal Chemical Research. P. J. Wilson, jun. (Blast Furnace and Coke Association of the Chicago District : Blast Furnace and Steel Plant, 1946, vol. 34, Dec., pp. 1537–1539). Aspects of the chemistry of coal distillation products on which research may prove necessary or profitable are indicated.—C. O.

Operation Morgantown. P. B. McCay. (Blast Furnace and Steel Plant, 1946, vol. 34, Nov., pp. 1396–1403, 1448–1449). A detailed description is given of the operations involved in the shutting down of two batteries of modern vertical underfired coke-ovens and their return to service ten months later. The ovens, at Morgantown, West Virginia, were sealed with the hot coke still inside and allowed to cool by radiation to the atmosphere. Very severe cracking of the walls was found when the ovens were cold. The cracks, which were up to 2 in. in width, were closed by controlled expansion during the heating-up process before the ovens were again charged.—C. O.

The Preparation of Coal and Coke for Coke Ovens and Blast Furnaces. C. L. Potter. (Year Book of the American Iron and Steel Institute, 1946, pp. 102–130). Typical American practice in preparing coal for coking and coke for use in the blast-furnace is described, with illustrated examples taken from the Pittsburgh district. Preparation may begin at the coal face by selective loading or hand-picking, but this is becoming more difficult with increased mechanization and the exploitation of poorer seams. The blending of coal, either underground in the tubs or on the surface in bins, to a uniform sulphur and ash content is of great importance. Rheolaveur and jig washers, hydrotators, classifiers, Deister tables, froth flotation, and heavy-media separation are all in common use for coal-cleaning. The blending of high- and low-volatile coals before coking has been found to be very advantageous in improving the properties of the coke and reducing the ash and sulphur contents. The coking process and the sizing of coke are discussed very briefly. —C. O.

Sulphuric Acid from Coke-Oven Gas. W. A. Leech, jun., and F. D. Schreiber. (Iron and Steel Engineer, 1946, vol. 23, Dec., pp. 93–101). Preparatory to a description of the hot-activation sulphur-recovery plant in operation at the works of the Pittsburgh Coke and Chemical Co., earlier methods for the removal of sulphur compounds from coal gas are discussed. By means of the hot-activation sulphur-recovery process the recovery of hydrogen cyanide and the production of sodium cyanide offer an attractive return. The scrubbed gas consists of hydrogen sulphide and carbon dioxide, and it is claimed that, with a hydrogen-sulphide concentration of 450 grains/100 cu. ft. of raw gas, the production of sulphuric acid can be a profitable undertaking.—J. R.

REFRACTORY MATERIALS

Details of the Quartz Transformation in Silica Bricks. P. J. Holmquist. (Proceedings of the Royal Swedish Academy of Engineering Sciences, 1947, No. 192). Microscopical methods were employed to study the transformation undergone by quartz in the firing of

silica bricks. Three or four different zones of transformation were formed by heating. The second of these had the character of a colloidal crystallization of cristobalite. The central and main product of the transformation was characterized by optical heterogeneity, but it also contained cristobalite in crypto-crystalline form, probably in combination with vitreous silica. Evidence was obtained that the transformation of quartz is accelerated by subordinate admixed substances and by gases. The firing gives rise to two different products: (*a*) the matrix, composed of a fine-grained mixture of tridymite and glassy slag, and (*b*) coarser grains, consisting mainly of cristobalite-silica, often containing remnants of untransformed quartz. This division persists after prolonged heating at high temperatures. Two different processes take place in the brick during heating; one is the crystallization of the SiO_2–CaO eutectic which forms the tridymite aggregate in the matrix, and the other is the action of this eutectic as a flux on the coarser grains, accelerating the formation of crypto-cristobalite. —R. A. R.

Considerations in Size Distribution of Clay Firebrick. J. A. Pierce. (Steel, 1947, vol. 120, Jan. 13, pp. 110–112). The difficulties arising from lack of uniformity in the size of firebricks for regenerator checker chambers are discussed. It has been found that the variation in size is greater between bricks from different manufacturers than among the products of one concern. The satisfactory building of open-weave checkers with a minimum risk of stoppage through dust accumulation depends upon very rigid control of the die-size by the manufacturer.—c. o.

Effect of Adding Alunite to Refractory Clays. J. O. Knížek and H. Fetter. (Journal of the American Ceramic Society, 1946, vol. 29, Dec. 1, pp. 355–363). The results of an investigation of the effects of additions of alunite on refractory clays are presented. In general, additions of less than 20% improve the characteristics of clays after firing; they decrease the shrinkage on reheating, increase the mechanical strength, and raise the softening point. Excessive additions of alunite, particularly in low-grade clays, cause swelling as a result of the evolution of sulphurous gases.—c. o.

Notes on Reaction Between MgO and Various Types of Refractories. C. L. Norton, jun., and B. Hooper. (Journal of the American Ceramic Society, 1946, vol. 29, Dec. 1, pp. 364–367). Tests are described in which samples of fused alumina, kaolin- and kyanite-based refractories, chrome-magnesite, silicon carbide, zircon, and fireclays containing 60%, 70%, 80%, and 90% of alumina were heated in contact with magnesia for 5 hr. at temperatures of 1205°, 1425°, and 1540° C. Silicon carbide and zirconia reacted slightly at 1540° C., but not at lower temperatures. Chromite, chrome-magnesite, forsterite, magnesite, and alumino-silicates containing more than 60% of alumina showed no reaction at 1540° C. —c. o.

36th Report of the Refractory Materials Joint Committee. (Gas Research Board, 1945, Communication No. 19). A report is presented on the work carried out during 1944–45 by the Joint Committee of the Gas Research Board and the British Refractories Research Association. Abstracts from the nine papers contained in the report follow.—c. o.

The Behaviour of Firebricks on Reheating—After-Contraction and After-Expansion under Oxidizing Conditions. F. H. Clews, J. F. Clements, and A. T. Green. (Gas Research Board, 1944–45, Communication No. 19, pp. 8–31). Data are presented on the changes in dimensions observed in twenty brands of "average" quality and three brands of aluminous firebricks which were heated at a rate of 5–6° C./min. in a reducing atmosphere up to 1400° C., at which they were maintained for 2 hr. It is concluded that certain fireclays can be made to expand or contract at will during reheating by varying the firing temperature and the fineness of their constituents.—c. o.

Study of the Clay-Quartz System—The Estimation of Quartz by Thermal Analysis Methods. R. W. Grimshaw and A. L. Roberts. (Gas Research Board, 1944–45, Communication No. 19, pp. 31–38). The results of tests of a method for determining quartz in systems using the temperature effect which accompanies the $\alpha \rightleftharpoons \beta$ inversion at 574° C. are discussed. It is concluded that this thermal-analysis method is a rapid and accurate one for estimating the proportion of quartz in mixtures with calcined china clay.—c. o.

Refractory Insulating Materials—Further Developments in the Application of Gradated Porosity. L. R. Barrett, J. F. Clements, J. Vyse, and A. T. Green. (Gas Research Board, 1944–45, Communication No. 19, pp. 38–49). Experiments with special types of gradated bricks are described. It is shown that gradated insulating bricks can be made sufficiently robust to withstand the wear and tear experienced at the back of a coke-grate.—c. o.

The Evaluation of the Properties of High-Temperature Insulating Materials—Studies of a Heat Dissipation Test for Insulating Materials. L. R. Barrett, J. Vyse, and A. T. Green. (Gas Research Board, 1944–45, Communication No. 19, pp. 49–73). An experimental investigation of the utility of the "heat-dissipation" test devised by A. Edwards for refractory insulating materials is described. The test, in which insulating power is measured on the basis of the amount of heat transmitted through an internally-heated tube of the refractory is considered to be a useful and rapid alternative to the full-scale thermal-conductivity test.—c. o.

The Action of Carbon Monoxide on Refractory Insulating Materials. L. R. Barrett, J. Vyse, and A. T. Green. (Gas Research Board, 1944–45, Communication No. 19, pp. 73–82). The results obtained in tests on five types of refractory brick exposed to pure carbon monoxide at 450° C. for 100 hr. are discussed. Both clay and diatomite bricks are liable to attack by carbon monoxide. Porous clay bricks and diatomite bricks free from metallic iron proved to be the most resistant to disintegration.—c. o.

Heat Transfer in Refractory Insulating Materials—Thermal Conductivity and Permeability as Related to Directional Properties. L. R. Barrett, J. Vyse, and A. T. Green. (Gas Research Board, 1944–45, Communication No. 19, pp. 82–88). An investigation into the directionality of certain properties of refractory bricks is described briefly. Experiments show that when the thermal conductivity of an insulating brick is different in two directions at right angles, the permeability is affected in a similar manner.—c. o.

Jointing Cements—The Effect of Water Content on the Strength of Joints. F. H. Clews, F. Ball, J. F. Clements, and A. T. Green. (Gas Research Board, 1944–45, Communication No. 19, pp. 88–97). Tests of the transverse strengths of standard joints made of three types of fireclay and two types of siliceous cements, containing varying proportions of water, are described. In general, the strength of joints increased with the water content of the cement over the whole experimental range, and the soundest joints were obtained with cements in the most fluid condition in which they could be applied.—c. o.

The Effect of Hydrocarbon Gases on Refractory Materials—The Composition of the Iron Spots in the Firebrick Specimens and of the Carbon Spots and Deposits Formed by Methane and Carbon Monoxide. E. Rowden. (Gas Research Board, 1944–45, Communication No. 19, pp. 97–104). An account is given of an investigation, using X-ray analysis, of the composition of the carbon deposits formed during the attack on firebricks by methane and carbon monoxide. The iron spots which are readily attacked consist of free iron oxides, the more resistant ones of complex silicate glass, hercynite, or fayalite. Methane reduces the iron oxide to metallic iron, iron carbide, or a mixture of the two, depending upon the temperature. Iron carbide is probably not the catalyst in this reaction. Carbon monoxide converts the iron oxide either to magnetite plus a little iron carbide or completely to iron carbide.—C. O.

Refractory Fire Backs—The Effect of Thickness of Tiles on Thermal Shock Resistance. L. R. Barrett and A. T. Green. (Gas Research Board, 1944–45, Communication No. 19, pp. 104–108). An account is given of tests made to determine the optimum thickness of flat tiles for maximum resistance to thermal shock. It was found that the resistance to shock decreased with tile thickness under conditions similar to those obtaining immediately behind the burning fuel in an open, domestic coke fire.—C. O.

37th Report of the Refractory Materials Joint Committee: 1945–46. (Gas Research Board, 1945–46, Communication No. 25). A report is presented on the work carried out in 1945–46 under the direction of the Refractory Materials Joint Committee set up by the Gas Research Board and the British Refractories Research Association. Abstracts of the seven papers contained in the report follow.—C. O.

The Behaviour of Firebricks on Re-Heating. After-Contraction and After-Expansion under Reducing Conditions. F. H. Clews, J. F. Clements, and A. T. Green. (Gas Research Board, 1945–46, Communication No. 25, pp. 8–15). The dimensional changes produced by re-heating 22 types of firebrick to 1400° C. under oxidizing conditions are described. In general the after-contraction is less, or the after-expansion is greater, when bricks are heated under oxidizing conditions than when they are heated under reducing conditions.—C. O.

The Behaviour of Firebricks on Re-Heating—Some Possible Modifications in the Re-Heat Test. F. H. Clews, J. F. Clements, and A. T. Green. (Gas Research Board, 1945–46, Communication No. 25, pp. 16–22). Tests of methods suggested for preventing the occurrence of after-expansions during re-heat tests are described. It was found that expansions can be prevented by the application of a small load to the specimen, but this method does not lend itself to standardization. No reheating test carried out at a single temperature can provide sufficient information to classify every type of brick. Tests on duplicate specimens at 1400° C. and 1250° C. are recommended.—C. O.

Refractory Insulating Materials—Experiments with Panels of Refractory Insulating Bricks Coated with Aluminous Grog-Clay Mixtures. W. F. Ford, J. Vyse, L. R. Barrett, and A. T. Green. (Gas Research Board, 1945–46, Communication No. 25, pp. 23–29). Tests of the slag-resisting, spalling, and reheating properties of firebricks coated with aluminous grog-clay mixtures are described.—C. O.

Refractory Insulating Materials—The Expansile Effect of Aluminium Powder on Fireclay Grog-Clay Coatings for Refractory Insulating Bricks. L. R. Barrett, J. Vyse, and A. T. Green. (Gas Research Board, 1945–46, Communication No. 25, pp. 30–38). Experiments with mixtures of aluminium powder and clay as coatings for firebricks are described. The metallic aluminium reduces the contraction on firing to a degree dependent upon the amount used and the physical properties of the powder,—C. O.

The Behaviour of Refractory Materials under Stress at High Temperatures—Experiments on the Relaxation of Porcelain in Torsion at Constant Deformation at 950° C. E. B. Colegrave, F. H. Clews, and A. T. Green. (Gas Research Board, 1945–46, Communication No. 25, pp. 39–47).

Study of the Clay-Quartz System—Thermal Analysis Methods; Experiments with Tridymite and Cristobalite. R. W. Grimshaw and A. L. Roberts. (Gas Research Board, 1945–46, Communication No. 25, pp. 48–52). Experiments on the thermal analysis of clay-quartz mixtures by measuring the temperature effects associated with the tridymite $\alpha \rightleftharpoons \beta$ inversion and the two characteristic cristobalite inversions are described.—C. O.

The Measurements of Temperatures in Gas Retorts—Records at Selected Positions In or Near to the Retort Wall. E. Heaton and A. T. Green. (Gas Research Board, 1945–46, Communication No. 25, pp. 53–70).

Foundry Refractories—Their Properties and Application. C. A. Brashares. (American Foundryman, 1947, vol. 11, Jan., pp. 41–45).—R. A. R.

Rammed Refractories. R. H. Zoller. (American Foundryman, 1946, vol. 10, Nov., pp. 67–69). The construction of rammed linings for electric steel furnaces and the drying of ladles are discussed.—R. A. R.

BLAST-FURNACE PRACTICE AND THE PRODUCTION OF PIG IRON

Production of Low Silicon Basic Iron in the Blast Furnace Using High Magnesia Slags. M. E. Nickel. (Blast Furnace and Coke Association of the Chicago District: Blast Furnace and Steel Plant, 1946, vol. 34, Dec., pp. 1522–1526). **Production of Low-Silicon Basic Iron Using High-Magnesia Slags.** M. E. Nickel. (Steel, 1946, vol. 119, Dec. 9, pp. 112–114, 158). An account is given of how the blast-furnace department at the Wisconsin Steel Works met a request from the open-hearth department for basic iron containing from 0·30% to 0·60% of silicon and 1·50% to 1·75% of manganese. After a thorough study of blast-furnace slags it was decided to operate No. 2 blast-furnace on a high-magnesia slag, with the object of producing the iron specified. The average analysis of the iron produced during the five-weeks' test period was: Silicon 0·48%, sulphur 0·043%, phosphorus 0·164%, manganese 1·55%, and the average iron temperature was well above 2700° F. Some of the benefits achieved in the open-hearth furnaces by the use of the low-silicon iron are enumerated.—J. R.

Electric Smelting Plant at Choindez, 1943. E. Gehrig. (Von Roll Mitteilungen, 1945, vol. 4, June, pp. 26–72). A very detailed and fully illustrated account is given of the construction in 1943 of a Tysland-Hole electric pig-iron furnace complete with sintering, gas-cleaning, and pig-casting equipment. The furnace hearth is 27 ft. in dia. × 15 ft. 7 in. high. About 8 tons of iron are tapped every 4 hr. The amount of coke required for reduction is about 400 kg./1000 kg. of iron and the electricity consumption is 3000 kWh./1000 kg. of iron. Operating data and experience gained in the first campaign are discussed.—R. A. R.

The Prospects for Electric Smelting. R. Durrer. (Von Roll Mitteilungen, 1945, vol. 4, June, pp. 73–74). After reviewing the conditions affecting the economy of the electric smelting of iron ores, the author shows that the

principal difficulty preventing the erection of new plants in Switzerland is the inadequate supply of hydro-electric power—a deficiency which is not likely to be made up in the next few years.—R. A. R.

PRODUCTION OF STEEL

Developments in the Iron and Steel Industry During 1946. W. H. Burr. (Iron and Steel Engineer, 1947, vol. 24, Jan., pp. 67–82). Iron and steel production and developments in iron and steel works equipment in 1946 are reviewed.—C. O.

Wartime Experiences in the American Steel Industry. H. L. Chamberlain. (Journal of the Birmingham Metallurgical Society, 1946, vol. 26, June, pp. 55–71). Some of the major advances in the theory and practice of steelmaking and steel processing made in America during the recent war are discussed. Particular reference is made to time-temperature-transformation diagrams, the Du Pont sodium-hydride descaling process, and induction heating.—C. O.

German Alloy Steel and Tool Steel Plants. (British Intelligence Objectives Sub-Committee, 1946, Final Report No. 997: H.M. Stationery Office). Brief surveys are made of the practice at three German works producing high-quality alloy and tool steels. The works are: Deutsche Edelstahlwerke, Krefeld; Gebrüder Bohler A.G., Buderich; and Gustav Grimm, Remscheid. —C. O.

The Effect of Temperature on the Phosphorus Reaction in the Basic Steelmaking Process. K. Balajiva and P. Vajragupta. (Journal of the Iron and Steel Institute, 1947, vol. 155, Apr., pp. 563–567). Following the previous laboratory investigation of the phosphorus reaction in the basic steelmaking process at 1585° C., the work has been extended to two other temperatures, *i.e.*, 1550° C. and 1635° C., employing in each case a series of slags of varying lime content and with compositions covering the normal range of basic practice. It is shown that, at steelmaking temperatures, the empirical relationship between the total lime content of the slag and the phosphorus equilibrium constant

$$k = \frac{(P_2O_5)}{[P]^2 \times (FeO)^5}$$

can be defined by the linear equation:

$$\text{Log } k = n \text{ log } \Sigma C_a O - c,$$

where the gradient n remains constant whilst c varies with temperature. Application of this relationship in controlling dephosphorization in industry is indicated. An X-ray examination of the rapidly quenched slags obtained in these experiments was carried out, and the results confirmed the findings previously reported for the work at 1585° C.—R. A. R.

The Effect of Temperature on the Equilibrium between Carbon and Oxygen in Molten Steel and in a Gas Phase. G. Phragmén and Bo Kalling (Iron and Steel Institute, 1947, Translation Series, No. 304). This is an English translation of a paper which was published in Jernkontorets Annaler, 1939, vol. 123, No. 5, pp. 199–218. (*See* Journ. I. and S.I., 1939, No. II, p. 327A).—D. R. S.

The Effects of Variations in Raw Materials on Basic Open Hearth Operations and Production. C. R. FonDersmith. (Year Book of the American Iron and Steel Institute, 1946, pp. 131–144: Blast Furnace and Steel Plant, 1946, vol. 34, Oct., pp. 1277–1283; Nov., pp. 1393–1395). The conclusions reached during twenty-nine years operation of the basic open-hearth furnaces of the American Rolling Mill Company on the effects of variations in raw materials on practice and production are outlined. The following raw materials are discussed: Pig iron; scrap; iron ore; limestone; fluorspar; refractories; and fuel.—C. O.

Preparation of Raw Materials for Fast Melting in an Electric Arc Furnace. S. D. Gladding. (Year Book of the American Iron and Steel Institute, 1946, pp. 94–101: Blast Furnace and Steel Plant, 1946, vol. 34, Nov., pp. 1404–1407). The charging and electrode control of electric steel furnaces are discussed briefly. The major factors in attaining proper control of the furnace operation, with consequent ability to increase melting rates, are a very exact scrap preparation and a method of charging which gives correct distribution and stratification of the charge. The objects of scrap preparation are sizing, raising the density of the scrap, and the removal of extraneous or harmful material. Slag-making and finishing additions should all be thoroughly dried at temperatures between 500° and 1200° F., in order to prevent hydrogen absorption in the bath.—C. O.

Oxygen-Accelerated Combustion. E. T. W. Bailey. (Iron and Coal Trades Review, 1947, vol. 154, Feb. 7, pp. 295–297). Experiments at the Hamilton works of the Steel Company of Canada, Ltd., with an open-hearth steel furnace are described. The furnace was 43 ft. 6 in. in length and 15 ft. 6 in. wide, with a nominal capacity of 175 tons. In the first tests the oxygen was passed in through a ¼-in. dia. copper tube parallel to the oil tube in the burner. Later the size of the oxygen tube was increased to 1-in. in dia., and ultimately the oxygen was admitted at a pressure of 5 lb./sq. in. through the annular gas passage of a burner designed for gas and oil burning. It was found economical to increase the fuel oil consumption from 370 to 500 gal./hr., using 700 cu. ft./min. of oxygen. The scrap-melting period was decreased by at least 2½ hr., and difficulty was experienced in keeping pace with scrap charging. The tests as a whole indicate a net saving in fuel consumption of about 17%.—C. O.

The Mechanism of the Carbon–Oxygen Reaction in Steelmaking. C. E. Sims. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2129: Metals Technology, 1947, vol. 14, Jan.). The qualitative relationships between carbon and oxygen in the bath of an open-hearth or electric steel furnace are discussed on the assumption of the solubility of carbon monoxide in steel.—C. O.

Use of Oxygen in the Open-Hearth Bath. G. V. Slottman and F. B. Lounsberry. (Iron Age, 1947, vol. 159, Feb. 20, pp. 42–45; Iron and Coal Trades Review, 1947, vol. 154, Mar. 7, pp. 363–366). An account is given of the first large-scale application of oxygen for carbon reduction in an open-hearth furnace bath, by the Allegheny Ludlum Steel Corporation. In large furnaces oxygen was fed at a pressure of 75–125 lb./sq. in. and a rate of 25,000–50,000 cu. ft./hr. into the bath through uncoated 1-in. steel pipes, with their nozzles maintained at a depth of 4–6 in. The efficiency of the oxygen, *i.e.*, the cubic feet of oxygen used per ton of steel to remove 0·01% of carbon, was 5·1 in the carbon range 0·20–0·10% and 7·0 in the range 0·20–0·06%, with rates of flow of 330–810 cu. ft./min. Attempts to remove large amounts of carbon in the high-carbon range by oxygen alone result in excessive heating of the bath, and in all carbon ranges care must be taken to avoid bottom boils and damage to the lining, but oxygen can be very useful in accelerating an ore reaction. Preliminary studies indicate that the cost of oxygen additions varies with the length of the boil and may be balanced by savings in time, fuel, ore, and limestone, as well as metal lost in the slag. The quality of the steel produced was no worse than normal, and no trouble was experienced with the refractories.—C. O.

Oil-Firing—Its Application to Open-Hearth Furnaces. G. R. Bashforth. (Iron and Steel, 1947, vol. 20, Jan., pp. 3–8). The characteristics of oil as a fuel for open-hearth furnaces are discussed, with particular reference to problems of burner design and methods of atomization. The main modifications in furnace design when changing from gas- to oil-firing concern the regenerators and port ends. Excellent results have been attained with oil-fired furnaces in America ; their application in Great Britain depends mainly upon the price of oil and the reliability of the oil supply.—C. O.

Liquid Fuel. C. Croxford. (National Trades Technical Societies : Iron and Steel, 1947, vol. 20, Feb., pp. 49–53 ; Mar., pp. 83–87). An account is given of the change-over from gas and tar firing to marine fuel oil for heating a 100-ton open-hearth furnace in South Wales. The advantages of liquid fuels, the training of men, the supply of fuel to the furnace, and the operating technique are dealt with in detail.—R. A. R.

Slag Control in the Basic Open-Hearth Steel Process. T. Colten. (Jernkontorets Annaler, 1946, vol. 130, No. 12, pp. 649–652). (In Swedish). This short paper serves to introduce the three comprehensive reports (abstracts of which follow) presented by members of the committee on slag control in basic open-hearth steelmaking, which was set up in 1942 by Jernkontoret. The first report of this series was presented by B. Mason (*see* Journ. I. and S.I., 1944, No. II, p. 69P). The present author, who is now chairman of this committee, concludes that it seems to be possible for the steelworks metallurgist to judge the composition of the slag by means of slag-cake tests which provide the simplest method of controlling the slag in the basic open-hearth process.—R. A. R.

Investigations of the Solid Solubility of the Oxides CaO, MnO, MgO, and FeO in Binary Systems. H. Petterson. (Jernkontorets Annaler, 1946, vol. 130, No. 12, pp. 653–663). (In Swedish). The solubility in the solid state in the binary systems CaO, MnO, MgO, and FeO has been studied with X-rays. The materials used were not the pure oxides but the corresponding carbonates and oxalates. These were prepared by mixing thoroughly in a mortar and ramming the powders into small cylinders. The samples were held at temperatures in the 900–1600° C. range and cooled fairly slowly. The X-ray examination showed that complete solubility most probably exists in the systems CaO–MnO, MnO–MgO, MgO–FeO, and FeO–MnO. These results are in accord with those obtained by Jay and Andrews (*see* Journ. I. and S.I., 1945, No. II, p. 15P). The solubility in the system CaO–MgO was found to be negligible, which also agreed with earlier investigations. A certain amount of mutual solubility was established in the system CaO–FeO.—R. A. R.

Investigations of Basic Open-Hearth Slags with the Metallurgical Microscope. H. Pettersson and S. Eketorp. (Jernkontorets Annaler, 1946, vol. 130, No. 12, pp. 664–677). (In Swedish). In order to follow the changes in the constitution of the slag during the melting process, polished specimens of slag taken at different stages from five heats of basic open-hearth steel were examined under a metallurgical microscope. Three of the heats were normal with slag basicities ($CaO/(SiO_2 + P_2O_5)$) ranging from 1·16 to 3·50 ; the fourth and fifth heats were high in manganese and phosphorus respectively. The effects of different oxides in the slag on its structure are explained and 32 micrographs of slags are reproduced. An attempt is made with the aid of a ternary phase diagram, based on that of the $CaO–MgO–SiO_2$ system, to depict the course of the solidification and explain the microstructure of slags.—R. A. R.

Judging the Quality of Basic Open-Hearth Slag by Means of Slag Cakes. H. Pettersson. (Jernkontorets Annaler, 1946, vol. 130, No. 12, pp. 678–701). (In Swedish). The possibility of estimating the composition of basic open-hearth slags from the appearance of slag cakes has been examined. Many slag samples were collected from different Swedish steelworks ; these were analysed and the appearance of cakes was studied. Six plates of photographs of samples are presented. The influence of certain factors on the appearance of the top and bottom surfaces and of fractured samples of slag cakes, and the manner in which the composition affects the appearance are discussed. The slags are divided into groups according to their basicity. It was found that the basicity could be estimated fairly accurately—the error seldom exceeding 10%, but it was more difficult to estimate the FeO content.—R. A. R.

Manufacture of Electrical Steel Sheets in Germany. (British Intelligence Objectives Sub-Committee, 1946, Final Report No. 1082 : H.M. Stationery Office). An account is given of the production in Germany of high-grade transformer steels. The best sheet, with a core loss of 0·90 W./kg. at a B_{max} of 10,000 gauss and a frequency of 50 cycles/sec., was made by Capito und Klein, in conjunction with Krupps, whilst Thyssens, Hamborn, who made 1·0 W./kg.-grade sheet were the largest producers, with over 18,000 tons in 1939. The highest qualities of transformer sheets were made exclusively from arc-furnace steel ; Krupps and Thyssen used the Duplex process in which basic open-hearth or basic-Bessemer steel is refined in the basic electric arc furnace. Full particulars are given of hot-rolling, annealing, and pickling practices, and reference is made to methods of insulation, stamping, and testing.—C. O.

Vacuum Melting in Germany. G. T. Motock. (Iron Age, 1946, vol. 158, Dec. 12, pp. 64–69). The plant and practice employed at the works of Heraeus Vacuumschmelze, Hanau, Germany, are described, with illustrations. Ring and vertical-crucible types of vacuum furnaces are used for melting ferrous and non-ferrous alloys free from oxidation, the occlusion of gases, or the solution of hydrogen and nitrogen.—C. O.

Electronic-Frequency Converting Equipment Used for Production Melting of Alloy Steels. (Industrial Heating, 1946, vol. 13, Dec., pp. 1990, 1992). A short account is given of the installation of a 300-kW. electronic frequency-changing equipment at Michigan City, Indiana. The equipment converts 3-phase, 60-cycle current into 1-phase, 1000-cycle current for use in two induction furnaces each capable of melting 650 lb. of alloy steel.—C. O.

HEATING FURNACES AND SOAKING PITS

Air–Fuel Ratio Controls Oil-Fired Soaking Pits. L. E. Browne. (Steel, 1946, vol. 119, Dec. 23, pp. 68–69). The main features of a soaking pit heated by products of combustion are described. The temperature of the neutral atmosphere controls the ratio of air to oil fuel in the burner, which is outside the pit.—C. O.

High Temperature Electric Tube Furnace. J. W. Gartland. (Transactions of the Electrochemical Society, 1945, vol. 88, pp. 121–132). The details of construction of an electrically heated carbon tube furnace are described. The furnace may be rapidly heated to 3,000° C. or any lower temperature, and held within ± 20° C. for several hours. At least half the resistor length provides uniform black-body conditions, suitable for optical-pyrometer calibration.—C. O.

Possible Uses of Microwaves for Industrial Heating. J. Marcum and T. P. Kinn. (Second National Electronics Conference: Product Engineering, 1947, vol. 18, Jan., pp. 137–140). The characteristics of electric currents with wavelengths of 1–100 cm. as sources of energy for dielectric heating are reviewed. The future applications of radio-frequency heating appear to be in the fields of the annealing of wire, the drying and "curing" of textile threads, and the canning of food.—C. O.

The Electric Infra-Red Process. J. C. Lowson. (Ministry of Fuel and Power, Fuel Efficiency Committee Conference on "Fuel and the Future," London, Oct., 1946). The use of infra-red rays emitted by incandescent electric lamps for industrial drying is discussed briefly, and compared from the standpoint of economy with the convection-drying process.—C. O.

Output Increased, Maintenance Reduced in New High Temperature Furnace. J. D. Knox. (Steel, 1947, vol. 120, Feb. 3, pp. 99, 122–124). A description is given of a gas-fired radiant-tube furnace designed for operation at temperatures up to 2500° F. The tubes and the hearth rollers are of silicon carbide, supported in a special way to minimize distortion. Natural gas is burned in ring-type luminous-flame burners at sub-atmospheric pressures.—C. O.

FORGING, STAMPING, DRAWING, AND PRESSING

The Modern Forging Operation. J. A. Over. (Association of Iron and Steel Engineers: Steel Processing, 1946, vol. 32, Dec., pp. 795–796, 805–806). The basic principles of the heavy forging of steel are summarized.—C. O.

New Gravity Drop Hammer Features Pneumatic Ram Lift. (Iron Age, 1947, vol. 159, Feb. 20, p. 47). A short description is given of a new type of gravity drop hammer with a pneumatically-lifted ram which enables 10–20% more blows per minute to be delivered than are possible with a board hammer.—C. O.

The Welded Steel Press. A. Clements. (Steel, 1947, vol. 120, Feb. 17, pp. 90–91, 112). Recent trends in the design of punch presses, in particular the use of welded construction, are discussed.—C. O.

Heavy Forging Equipment. Notes on German Heavy Hydraulic Forging Presses. (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 821: H.M. Stationery Office). Illustrations and descriptions are given of the hydraulic forging presses of more than 1,500 tons capacity which have been inspected in Germany.—C. O.

German Methods of Forging and Machining H.E. and A.P. Shell. (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 890: H.M. Stationery Office). Details are given of the reheating, forging, machining and heat-treatment processes employed at nine German works making high-explosive and armour-piercing shell. Notes on making the driving bands by powder metallurgy are included.—R. A. R.

German Manufacture of Agricultural Machine Parts. (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 915: H.M. Stationery Office).—R. A. R.

Forging and Heat-Treatment Technique at Some Major German Factories. (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 1112: H.M. Stationery Office).

Fabrication of the Japanese Samurai Sword. S. V. Grancsay. (Army Ordnance: Iron Age, 1947, vol. 159, Jan. 9, p. 61). A brief account is given of the manufacture of the Japanese Samurai sword blade, which has an extremely hard and keen edge and a relatively soft centre. Billets carefully prepared by welding together alternate layers of iron and steel are hand-forged by skilled craftsmen in operations lasting sixty days. —C. O.

Synchronized Stamping and Plating. D. Dewey. (Steel, 1947, vol. 120, Feb. 3, pp. 94–96). A brief description is given of the stamping and nickel and chromium-plating equipment used by the Eaton Manufacturing Company, Cleveland, in producing motor-car components, such as hub and radiator caps, at the rate of 15,000/day. —C. O.

How to Select Die Blocks. R. G. Sartorius. (Iron Age, 1947, vol. 159, Jan. 23, p. 51). Data are given on the types of forging for which various commercial alloy-steel die blocks are suitable.—C. O.

Forging Die Design. J. Mueller. (Steel Processing, 1946, vol. 32, Nov., pp. 712–714). A description is given of the series of operations needed to forge two connecting rods in line from one steel blank, with explanations of the factors which influence the design of the edging, roughing, and finishing dies.—C. O.

Forging Die Design. J. Mueller. (Steel Processing, 1947, vol. 33, Jan., pp. 22–25). The design of the dies and the technique for press-forging various articles are discussed.—R. A. R.

Ford Axles Forged from Rolled Uses. (Machinist, 1947, vol. 90, Jan. 25, pp. 1689–1693). An illustrated description is given of the production at the Dagenham works of the Ford Motor Company, Ltd., of front axles for small cars. The blanks (or "uses") for the final forging are prepared by rolling at the rate of 750/hr. The channel section of the axle is formed in the finishing rolls, leaving only the ends to be shaped by forging, thus reducing the wear on the press.—C. O.

Stainless-Clad Stampings Enter the Automotive Industry. (Steel Processing, 1946, vol. 32, Nov., pp. 710–711, 723). The use of stainless-steel-clad steel for stampings for motor cars is discussed. The clad steel may be made by casting mild steel around stainless steel plates or by rolling. Its forming properties are very similar to mild steel.—C. O.

Roll Design for Die Rolling. T. N. Sloan. (Iron and Steel Engineer, 1946, vol. 23, Dec., pp. 87–90). Die rolling is defined, and the equipment and methods used for the production of automobile crankshafts, camshafts, connecting rods, axles, etc. by this process are described. —J. R.

Hot-Spinning Operations on Heavy Metal Heads. C. H. Wick. (Machinery, 1947, vol. 70, Jan. 2, pp. 3–8). A short account is given of modern practice in forming curved circular shapes, such as the heads of pressure vessels, by the hot-spinning of steel or non-ferrous metal plates.—C. O.

The Application to Shaping Processes of Hencky's Laws of Equilibrium. E. Siebel. (Journal of the Iron and Steel Institute, 1947, vol. 155, Apr., pp. 526–534). The increase in pressure along slip lines, and the relationship between the mean pressure and the principal stresses as well as between the slip line and the stress trajectories are discussed. Rules regarding the formation of slip lines are outlined. Slip-line systems and stress conditions on compression, and the resistance to flow between rough plates with constant and with varying friction at the compressing surfaces are analysed, allowing for the form of the free surface on compression. The gradual advance of slip layers in direct compression processes is explained and diagrammatically illustrated. Slip lines and stress conditions in cupping and related processes are described, and consideration is given to die friction and the cohesion of the metal. Slip lines and stress conditions in pressing

processes are elucidated, followed by a discussion on the various systems of slip layers. The effect of work-hardening is explained mathematically.

German Practice in Cold Shaping of Steel. (Steel Processing, 1947, vol. 33, Jan., pp. 33–35). The German practice of deep-drawing and extruding bonderized steel is described.—R. A. R.

Extrusion Presses for Metals. O. Schnyder. (Von Roll Mitteilungen, 1946, vol. 5, Dec., pp. 74–78). The principles of several types of piercing presses are explained and some large presses are described and illustrated. —R. A. R.

The Production of Seamless Hollow Bodies. O. Schnyder. (Von Roll Mitteilungen, 1946, vol. 5, Dec., pp. 79–85). The principles of the Ehrhardt and Klus piercing processes are explained and illustrated descriptions are given of (*a*) a 400-ton piercing press for hollow shells up to 200 in. outside dia.; (*b*) the Klus horizontal drawing press for long tubes; (*c*) the Klus combined piercing and drawing press for bodies up to 120 mm. in dia.; and (*d*) a high-speed hydraulic press with revolving-table feed.—R. A. R.

Hydraulic Deep-Drawing Presses. O. Schnyder. (Von Roll Mitteilungen, 1946, vol. 5, Dec., pp. 86–90). The principles of the Klus hydraulic deep-drawing press with a pneumatic ejector are explained.—R. A. R.

The Klus Sirius Central-Heating Radiator and the Machines for Making It. M. Koenig. (Von Roll Mitteilungen, 1946, vol. 5, Dec., pp. 97–101). A novel and efficient type of central-heating radiator and its advantages are described and details are given of its manufacture. A special folding machine was designed for making deep corrugations in flat steel sheets. Each radiator is made of a pair of these sheets electrically welded together and incorporating ducts along the top and bottom. The hydraulic folding and drawing press is described.—R. A. R.

The New Klus Easily Operated Control for Large Forging and Piercing Presses. O. Schnyder. (Von Roll Mitteilungen, 1946, vol. 5, Dec., pp. 102–104). A description is given of a means of controlling 1000-ton forging presses. The mechanism is driven by an oil pump; it is rapid in action and requires little effort by the operator. —R. A. R.

Improvements in the Construction of Forging and Piercing Presses. O. Schnyder. (Von Roll Mitteilungen, 1946, vol. 5, Dec., pp. 108–109). A brief description is given of an oil hydraulic valve-operating mechanism for controlling heavy presses.—R. A. R.

Accumulators. O. Schnyder. (Von Roll Mitteilungen, 1946, vol. 5, Dec., pp. 110–114). Devices for the control of hydraulic accumulators for supplying power to pressing shops are described, with special reference to the automatic control of a pump which ensures the adequate supply of high-pressure water.—R. A. R.

High-Speed Valveless High-Pressure Oil Pumps. O. Schnyder. (Von Roll Mitteilungen, 1946, vol. 5, Dec., pp. 115–123). A description is given of the "Hydro-Titan" high-speed high-pressure oil pump for feeding hydraulic presses.—R. A. R.

Tests to Determine and Predict the Drawing Force in the Bright-Drawing of Steel. W. Lueg and A. Pomp. (Iron and Steel Institute, 1947, Translation Series, No. 302). This is an English translation of a paper which was published in Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1944, vol. 27, No. 4, pp. 43–52. (*See* Journ. I. and S.I., 1945, No. II, p. 9A).—D. R. S.

Cold Finished Bar Steel. T. D. Taylor. (Iron and Steel Engineer, 1946, vol. 23, Dec., pp. 70–73). The evolution of the cold-finished-bar industry is reviewed. The increasing requirements of industry have led to the development of new types of steel and new methods to process them, and such steels and methods are discussed.—J. R.

Tungsten Carbide Draw Dies. R. Saxton. (Metallurgia, 1946, vol. 35, Dec., pp. 68–69). A short account is given of the design and preparation of tungsten-carbide dies for drawing steel.—C. O.

The Drawing of Steel Wire. J. F. Luckman. (Journal of the Birmingham Metallurgical Society, 1945, vol. 25, Dec., pp. 257–274). An outline is given of the history of wire-drawing, followed by an account of modern practice in drawing steel wire.—C. O.

Mill Practice—The Care and Maintenance of Dies. R. R. Preston. (Wire and Wire Products, 1946, vol. 21, Dec., pp. 957–960, 996–997). An outline is given of the preparation of stock for wire-drawing, the lubrication of dies, and methods of increasing die life. It is emphasized that careful cleaning and thorough maintenance are essential if a mill is to work at its maximum efficiency. —C. O.

MACHINERY FOR IRON AND STEEL PLANT

Trends in Electrical Equipment for Steel Mills. G. E. Stoltz. (Iron and Steel Engineer, 1946, vol. 23, Dec., pp. 61–66). The development of electricity as a source of power for steel mills is reviewed, and present and possible future trends are discussed.—J. R.

Iron, Steel and Non-Ferrous Metal Works Plant and Machinery. (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 527 : H.M. Stationery Office). This is a report on visits to German iron, steel, and non-ferrous metal works to investigate the technical progress in design and operation of equipment. It is in three sections covering (1) blast-furnaces, (2) melting-shop equipment, including open-hearth and electric furnaces, and (3) rolling mills and auxiliary equipment.—R. A. R.

Ore Dock Unloading Capacity. H. E. Reinhold. (Steel, 1947, vol. 120, Feb. 10, pp. 114–117). A brief description is given of the electrical equipment at the ore dock of the Carnegie-Illinois Steel Corporation. Electrical power loss in transmission is reduced to a minimum by installing the rectifiers in concrete vaults beneath the ore piles.—C. O.

Design and Air-Conditioning of a Full-Vision Crane Cab. R. Darrah. (Iron and Steel Engineer, 1947, vol. 24, Jan., pp. 117–122). A detailed description is given of the design of the cab of a stripping crane at the River Rouge plant of the Ford Motor Company. The walls of the cab are constructed of heat-absorbing glass and the ventilating system provides filtered air at a temperature of 60–65° F.—C. O.

Planning a Plant Layout. R. Spurgin, jun. (Iron Age, 1946, vol. 158, Dec. 19, pp. 73–75). Simple procedures for determining the optimum arrangement of machinery and equipment in a new plant are outlined. —C. O.

The Diesel-Electric Locomotive in Steel Plant Service. J. W. Brauns. (Iron and Steel Engineer, 1946, vol. 23, Nov., pp. 83–86). The operation of the Diesel-electric locomotive is briefly explained. Small locomotives of this type, weighing from 20 to 80 tons, are tending to replace steam locomotives in steel plants in the United States because of their low fuel costs, simple maintenance, ease of operation, and cleanliness. Examples are given of the experiences of various American firms with Diesel-electric engines.—C. O.

The New Jaw Crusher "von Roll," Klus, Type AJ. G. Jordi. (Von Roll Mitteilungen, 1946, vol. 5, Dec., pp. 139–148). A detailed description is given of a high-speed crushing machine suitable for limestone, etc. The eccentric drive of this machine gives the jaw a vertical as well as a horizontal motion, and it is designed so that the horizontal movement is greater at the bottom of the jaw than at the top. The product (force × distance) is approximately constant at all positions from top to bottom of the jaw, and this enables the dimensions of the flywheel to be reduced.—R. A. R.

The New Adjustable Vibrating Screen "von Roll," Klus, for Coarse and Fine Screening. G. Jordi. (Von Roll Mitteilungen, 1946, vol. 5, Dec., pp. 149–155). A new design for screening tables is described and illustrated. The design provides for a wide degree of control of the vibration as well as of the horizontal movement of the material along the screen.—R. A. R.

Ball Bushings Minimize Friction in Linear Motion. L. H. Leonard. (Steel, 1947, vol. 120, Jan. 27, pp. 74–75, 116). The operating principles and applications of a new type of bushing for round shafts moving with linear oscillation are discussed. The bushing comprises from 3 to 6 rectangular tracks arranged along the axis of the shaft, each track containing a series of balls which roll in continuous circulation.—C. O.

LUBRICANTS AND LUBRICATION

Lubrication in Iron and Steel Works Engineering. H. J. Knight. (Journal of the Iron and Steel Institute, 1947, vol. 155, Mar., pp. 423–430). The author has recently visited American steelworks where he studied the manner in which lubrication systems have been improved to keep pace with the increased speed of production. Descriptions of these improvements are given; they cover: (*a*) Centralized greáse-pumping systems which lubricate from one position all necessary points on a battery of blast-furnaces; (*b*) lubrication of steel-furnace gas regulators with a good solvent-extracted oil; (*c*) supplying oil to mill-motor bearings by a separate system with adequate continuous-cleaning and filtering equipment; and (*d*) the use of one oil for the gears, pinions, and bearings of a rolling mill. In conclusion the properties of oils and greases, the use of synthetic-resin roll-neck bearings, and the requirements of a good rolling oil are discussed.—R. A. R.

Deutsche Vacuum Oel A.G., Hamburg, Germany. Fuels and Lubricants. (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 967: H.M. Stationery Office). Details are given of the refineries operated by Deutsche Vacuum Oel A.G., together with information on the finished products and how they are prepared. The equipment available in the chemical, industrial, and engine laboratories is described with details of the test methods employed. A list of research and test reports is included; these can be obtained through the North German Oil Control.—R. A. R.

Metal Powder Self-Lubricating Bearings. A. J. Langhammer. (Iron and Steel Engineer, 1947, vol. 24, Jan., pp. 93–95). The applications of self-lubricating powder-metal bearings are discussed. Their main advantages over solid bearings are their high factor of safety when left unattended, cleanliness, long life, ease of assembly, and cheapness.—C. O.

Lubricating Hot Strip Mills. A. F. Brewer and W. H. Mandy. (Steel, 1946, vol. 119, Dec. 9, pp. 90–93, 154–156; Dec. 16, pp. 94–96, 140). In the first part of the article the lubrication of individual parts of rolling mills operating at high speeds and high temperatures is discussed. The second part deals with problems of application and maintenance encountered when using grease and fluid oils as lubricants.—C. O.

Selecting Correct Lubricants for Steel Mill Equipment. A. E. Hickel. (Steel, 1947, vol. 120, Feb. 24, pp. 106–114). Specifications of oils and greases for different applications in the rolling mill are given.—R. A. R.

Reclamation of Oils. J. D. Lykins. (Iron and Steel Engineer, 1946, vol. 23, Oct., pp. 69–74). The undesirable characteristics imparted to lubricating oils by contamination during working are enumerated, and methods of purification are described. Examples are given of batch and continuous cleaning, and of systems incorporating both methods.—C. O.

Corrosion Inhibitors versus Lubricating Characteristics of Diesel Engine Lubricating Oils. I. C. de Martonfalvy. (Mechanical World, 1946, vol. 120, Nov. 22, pp. 588–591). The problem of effecting a compromise between the corrosion-inhibiting and the lubricating properties of Diesel-engine lubricating oils is discussed.—C. O.

MACHINING AND MACHINABILITY

The Mechanism of Tool Vibration in the Cutting of Steel. R. N. Arnold. (Journal and Proceedings of the Institution of Mechanical Engineers, 1946, vol. 154, Dec., pp. 261–276). A report is given of investigations into the fundamental causes of vibration in cutting tools. This vibration may be self-induced, a function of the cutting properties of the metal and the sharpness of the tool, or forced, because of the interference of the tool with the surface cut during previous revolutions. The amplitude of vibration appears to be independent of the depth of cut, and to be limited to a value slightly in excess of that which makes the maximum vibrational velocity at the tool point equal to the speed of the work. It is affected to some extent by the damping characteristics of the tool shank.—C. O.

New Standard on Tool Life. O. W. Boston. (Industrial Standardization: Steel, 1947, vol. 120, Feb. 3, pp. 112–116, 162–164). New American standards for testing single-point machine tools of materials other than sintered carbides are summarized, and data are presented on the performance which may be expected from cutting tools.—C. O.

Cylinder-Liner Production. (Machinery, 1947, vol. 70, Jan. 23, pp. 99–105; Feb. 6, pp. 171–173). A detailed illustrated description is given of the production of steel cylinder liners by the Ford Motor Company in the United States. Circular blanks, 0·045 in. thick and $10\frac{1}{8}$ in. in dia., of low-carbon steel, the scrap from the manufacture of motor-car bumpers, are copper-plated, drawn in six operations, trimmed, flanged, burnished, heat-treated in an atmosphere of hydrocarbon gases and ammonia, and finally honed to the required surface finish.—C. O.

The Machining of Stainless Steels. W. H. Crisp. (Engineering, 1946, vol. 162, Nov. 29, pp. 526–528). The general characteristics of stainless steels in regard to work-hardening and chip formation are discussed. Modifications of standard machine tools to accommodate them to the special conditions obtained in machining stainless steels are recommended.—C. O.

Machining of Stainless Steels. W. H. Crisp and W. Burnan. (Machinery, 1947, vol. 70, Jan. 2, pp. 9–13). Recommendations are given for the choice, set-up, and maintenance of tools for machining ferritic, martensitic, and austenitic stainless steels.—C. O.

Needle Production. (Machinery, 1946, vol. 69, Nov. 21, pp. 651–656). Continuation of a previous article (*see* Journ. I. and S. I., 1947, vol. 155, Jan., p. 152). After leaving the stamping and eyeing machine, the needles are separated and the eye-ends are ground,

to complete the machining operations. Heat-treatment is carried out in gas-fired furnaces with slightly reducing flames. After quenching, the needles are very thoroughly scoured with emery and soap before the nickel-plating process begins. About 95% of needles are nickel-plated, the remainder being bright-polished. "Heading," or arranging the needles to lie in the same direction, is done by machine for large needles, but hand heading is still employed for very fine or special needles.—C. O.

Machinability—A Coil Test for Material Selection. E. J. Baty. (Iron and Steel, 1947, vol. 20, Jan., pp. 23–25). A tentative theory is advanced to account for the success of a method of sorting machinable from unmachinable steel bars by passing them through a solenoid and observing the resulting changes in magnetic field with a search coil.—C. O.

Some Metallurgical Factors Which Affect Machinability. K. J. B. Wolfe. (Metal Treatment, 1946, vol. 13, Winter Issue, pp. 225–247). A series of tests was made to ascertain why the machinability of many steels is markedly improved by a double-tempering and oil-quenching treatment, with the second temper some 25° C. lower than the first one. The tests, which are described in detail, were performed on four straight-carbon steels with carbon contents of 0·15–0·90%, and seven alloy steels; they included determinations of mechanical properties, microstructure, hardness, magnetic properties, residual stresses, and of the temperature of chip and tool developed during cutting. The improvement in machining properties was most marked in the oil-hardening steels of the higher-alloy types, and under heavy-duty machining conditions. The improvement is attributed to a slight softening, a more favourable microstructure, resolution and reduction of micro and macro internal stresses, decrease in work-hardenability, and a decrease in the friction between chip and tool and in the internal friction of the steel during chip formation.—C. O.

Toward Longer-Lived Abrasives. (Steel, 1946, vol. 119, Dec. 2, pp. 104–105, 142–146). The properties of a newly developed alumina abrasive known as 32 Alundum are described in detail. Very irregularly shaped alpha alumina crystals, with sharp points and re-entrant angles, are grown in a chemically unstable matrix of sulphide glass in an electric furnace. No subsequent crushing or milling is required, the matrix being removed by leaching with water. Compared with other alumina abrasives, 32 Alundum cuts at a faster rate and with less generation of heat.—C. O.

New Abrasive Reduces Grinding Costs. J. Anthony. (Iron Age, 1946, vol. 158, Nov. 21, pp. 56–59). The properties of a new alumina abrasive, 32 Alundum, are described. (*See* preceding abstract).

Prevention of Accidents in Sawing and Milling in the Metal Industry. G. Pawlitzki. (Technik, 1946, vol. 1, Sept., pp. 135–140). Many examples of guards and other safety devices fitted to sawing and milling machines are described and illustrated.—R. A. R.

Control and Measurement of Surface Finishes. J. A. Broadston. (Steel, 1947, vol. 120, Jan. 13, pp. 82, 116–121). The influence of surface finish on the design and manufacture of metal parts is discussed. There are no universally recognized standards of roughness, nor is there commercially available any instrument capable of giving consistent and dependable measurements of surface finish. The need for close control of finish in machine shops has been met by the use of arbitrarily chosen standard reference samples, with which comparison is made visually, by touch, or by instruments. —C. O.

X-Ray Diffraction Analysis of Cold Work Produced by Face Milling. F. Zankl, A. G. Barkow, and A. O. Schmidt. (Iron Age, 1947, vol. 159, Jan. 23, pp. 44–50). Experiments to determine the amount of cold work produced in metals by face-milling are described. Back-reflection X-ray diffraction photographs were taken of the machined surfaces of Dowmetal and steel specimens immediately after milling and after the removal of successive 0·001-in. layers in dilute hydrochloric acid solution. The conclusions reached were: (1) More cold work is done and the depth of penetration of deformation is greater when milling with negative radial rake angle cutters than with positive angle cutters; (2) a positive secondary radial rake angle reduces the amount of cold work caused by a negative primary radial rake angle; and (3) there is little difference in the depth of cold work produced in Dowmetal by cuts taken at the same feeds but at different depths.—C. O.

CLEANING AND PICKLING

The Chemical Basis of Pickling. H. Bablik. (Sheet Metal Industries, 1947, vol. 24, Feb., pp. 307–310). Fundamental physico-chemical phenomena affecting the pickling of steel are considered. The forces binding the atoms together in crystals of iron oxide have the character of ionic bonds, whereas in the case of metallic iron, metallic linkage is the characteristic; the significance of this is explained. The influence of an addition of a salt on the rate of solution of FeO and Fe_2O_3 in acids is discussed.—R. A. R.

On the Mechanism of Metal Cleaning. S. Spring and Louise F. Peale. (Metal Progress, 1947, vol. 51, Jan., pp. 102–106). An account is given of a study of the mechanism of the removal of oil from metal surfaces. Observations under the microscope reveal four stages in the process: Shrinkage of the oil film; gathering together of the oil; formation of globules; and removal of the globules. Evidence obtained in tests with cleaning solutions of varying alkalinities on oils of varying acidities does not support the saponification and emulsification theories of cleaning.—C. O.

Improvements in Tinning. H. C. Rodgers. (Iron and Steel Engineer, 1947, vol. 24, Jan., pp. 65–66). A short description is given of the equipment used at the Fairfield Tin Mill, Alabama, for pickling steel sheet before tinning. The sheets are fed by a vacuum-cup mechanism into a rubber-lined tank containing the pickling solution (0·5–1·5% of hydrochloric acid in water). A direct current of 100–300 amp., 6–12 V., is passed through the tank, with the sheet as cathode. The hydrogen evolved on the steel surfaces tends to remove oxide and expose the metal to the attack of the acid.—C. O.

De-Enameling. G. H. Spencer-Strong. (Steel Processing, 1946, vol. 32, Nov., pp. 719–723). Descriptions are given of processes for the removal of enamel from steel by the action of molten caustic soda, boiling caustic soda solutions, hydrochloric and sulphuric acids, and anhydrous hydrogen fluoride, and by sand-blasting. It is considered that de-enamelling is worthwhile in the case of complicated and expensive parts, but not as a general practice, especially if chemical methods, which lead to a deterioration in properties, are used.—C. O.

Annealing, Pickling, Washing and Liming of Rolled Steel Wire. E. R. Thews. (British Intelligence Sub-Committee, 1947, F.I.A.T. Final Report No. 837: H.M. Stationery Office). The problems associated with scale formation and removal during the rolling and annealing of steel wire before drawing are discussed. Reference is made to the control of sulphur and carbon in furnace gases, the selection of pickling methods, liming, and the

elimination of hydrogen embrittlement. A short description is given of a pickling process developed by Ungersböck, in which the steel is suspended between the anode and cathode of an electrolytic bath containing hot saturated ferrous-sulphate solution through which a small direct current is passed.—C. O.

Contribution to the Regeneration of Pickling Solutions. E. R. Thews. (British Intelligence Objectives Sub-Committee, 1946, F.I.A.T. Final Report No. 803, H.M. Stationery Office). The effect of accumulations of ferrous sulphate and ferrous chloride in pickling solutions, and methods of prolonging the useful life of the solutions are discussed. Four regeneration processes are outlined.—C. O.

PROTECTIVE COATINGS

Hard Chrome Plating Finds Wide Use at Ford. H. Chase. (Iron Age, 1947, vol. 159, Jan. 30, pp. 51–53). An illustrated account is given of the techniques used at the River Rouge plant of the Ford Motor Company for coating metal parts with hard chromium plating.—C. O.

Effect of Lead in Hot-Dip Galvanizing Baths. W. G. Imhoff. (Iron Age, 1947, vol. 159, Jan. 9, pp. 46–49). After enumerating the sources from which lead may enter galvanizing baths, the influence of the lead on the properties of zinc coatings is discussed. It is considered that lead is in general beneficial, as its presence gives smoother and more lustrous coatings, and causes the bath to be thinner and more fluid. The absence of lead greatly magnifies the deleterious effect of iron in the zinc.—C. O.

Dross Production in Metal Galvanizing. E. R. Thews. (British Intelligence Objectives Sub-Committee, 1947, F.I.A.T. Final Report No. 880 : H.M. Stationery Office). Twenty-five factors influencing the formation of "hard" zinc and dross during hot-dip galvanizing are discussed. —C. O.

Effect of Metallic Additions and Impurities on the Galvanizing Properties of Zinc. E. R. Thews. (British Intelligence Objectives Sub-Committee, 1947, F.I.A.T. Final Report No. 883 : H.M. Stationery Office). Problems due to impurities in zinc used for hot-galvanizing are discussed, and an analysis is made of the beneficial and detrimental effects of lead, iron, aluminium, tin, cadmium, antimony, and arsenic.—R. A. R.

Electro-Tinplate. Part I—The Influence of Plating Conditions on the Quality of Electro-Tinplate Deposited from the Stannous Sulphate Bath. R. M. Angles, K. W. Caulfield, and R. Kerr. (Journal of the Society of Chemical Industry, 1946, vol. 65, Dec., pp. 430–433). The properties of electro-tinplate deposited from stannous-sulphate/cresolsulphonic-acid baths were studied with regard to the effects of the tin and cresolsulphonic acid contents and the temperature of the bath, the current density, and the addition of wetting agents. The plated specimens were subjected to thiocyanate, (modified) hot-water, humidity-chamber, outdoor-exposure, and salt-spray tests, which led to the following conclusions : The quality of the coating improves as the concentration of tin in the bath is raised from 15 to 40 g./litre. There is an optimum concentration of cresolsulphonic acid, depending on the tin content. Raising the temperature of the bath as well as increasing the current density impair the quality of the coating. The addition of commercial wetting agents does not cause any significant improvement.—D. R. S.

Hot-Dipping and Electro-Deposition of Tin and Tin Alloys in Germany. (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 995 : H.M. Stationery Office).—R. A. R.

Progress in the Tin Consuming Industries. J. Ireland. (Metallurgia, 1946, vol. 35, Dec., pp. 97–100). A short survey is given of the developments in the tinplate industry during 1945 and 1946. The use of a tin coating as a pre-treatment before painting, the "Protecta-tin" process, electro-tinning, and the electrodeposition of tin alloys are discussed.—C. O.

Developments in the Use of Tin as a Protective Metal. E. S. Hedges. (Sheet Metal Industries, 1947, vol. 24, Feb., pp. 311–318).—R. A. R.

Phosphate Treatment of Wearing Surfaces. R. E. Shaw. (Institute of Marine Engineers : Iron and Coal Trades Review, 1947, vol. 154, Jan. 17, p. 133). The application and uses of phosphate coatings are discussed, with special reference to the phosphate treatment of wearing surfaces. Apart from the advantages of such coatings as an aid to lubrication, their corrosion-resistant properties are valuable and their use provides a safety factor combining rust resistance and insurance against premature failure owing to scuffing or seizing.—J. R.

Formation and Application of Phosphate Coatings. V. M. Darsey and W. R. Cavanagh. (Electrochemical Society, 1946, Preprint 91–1). The development of various phosphatizing processes is outlined and the application of phosphate coatings reviewed, special reference being made to their recent use as an aid in the drawing of metals.—D. R. S.

Metallizing Serves Many Industrial Needs. G. C. Close. (Steel Processing, 1946, vol. 32, Nov., pp. 715–718, 729). Methods which may be used to prepare surfaces for coating by the metallizing process are described. Rough and clean surfaces are essential since only a mechanical bond is formed during metallizing, which involves the spraying in a stream of air of metal wire melted in an oxy-acetylene flame. The process is applied mainly for the reconditioning or rebuilding of worn or damaged parts and the prevention of corrosion.—C. O.

Protective Metallic Coatings on Metals. W. R. Burrow. (Australian Institute of Metals : Australasian Engineer, 1946, Dec. 7, pp. 48–60). An account is given of the mechanism of metallic corrosion, the production of metallic coatings by immersion, spraying, and electrolysis, the testing of coatings by chemical and physical methods, and the protective value of individual coatings. A list of 61 references is appended.—C. O.

High-Temperature Protection for Mild Steels. W. N. Harrison, D. G. Moore, and J. C. Richmond. (Steel, 1947, vol. 120, Feb. 10, pp. 92–93, 120–122). An account is given of the development, testing, and production of a ceramic coating with high resistance to spalling under repeated thermal shock and with resistance to oxidation during prolonged exposures at temperatures up to 1250° C. The coating consists of a conventional ground-coat frit mixed with 20% of alumina.—C. O.

Problems in Porcelain Enamelling. Non-Enamelling Sheets. W. A. Deringer. (Porcelain Enamel Institute : Steel Processing, 1947, vol. 33, Jan., pp. 26–32). Owing to the shortage of enamelling-quality steel sheets other qualities are being used and enamelling difficulties are experienced ; these difficulties, and methods of overcoming them are discussed.—R. A. R.

The German Vitreous Enamel Industry. (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 788 (Appendix) : H.M. Stationery Office).—R. A. R.

Enamel Spraying Technique. A. J. Biddulph. (Institute of Vitreous Enamellers : Foundry Trade Journal, 1947, vol. 81, Feb. 6, pp. 133–135). A general survey of the equipment and techniques used in spraying enamel is given.—C. O.

New Enameling System. (Steel, 1947, vol. 120, Feb. 17, pp. 92–93, 128). The ovens used at the Dodge works of the Chrysler Corporation, Detroit, for baking the enamel finishes on motor-car bodies are described. The ovens are heated by continuously-circulated air, forced in through nozzles in the roof to create turbulence and ensure uniform temperature.—C. O.

Properties of Enamel Slips: Soluble Salts in Enamel Slips. B. W. King, jun., H. D. Carter, and H. C. Draker. (Journal of the American Ceramic Society, 1947, vol. 30, Jan. 1, pp. 22–26). Information is given on the soluble salts found in liquors obtained on milling a number of different commercial porcelain-enamel frits. The liquors were found to consist mainly of Na_2O, B_2O_3, and NaF, and the effect of varying the proportions of these compounds on the properties of the enamel slips was studied. —R. A. R.

Bituminous Coatings for the Protection of Iron and Steel Against Corrosion. R. St. J. Preston. (Department of Scientific and Industrial Research, 1946: Chemistry Research Special Report No. 5). Bituminous compositions used as protective coatings—including blends with oils, resins, rubber, and waxes—are classified, and their value for the protection of iron and steel against corrosion during immersion is reviewed critically. Special consideration is given to protection against fouling by marine organisms, and the physical and chemical characteristics desirable in coatings for this purpose are described. Examples are given of the use of compounds developed for chemical warfare as deterrents of marine fouling. The bibliography comprises 256 references. —M. A. V.

German Acetylene Chemical Industry—Corrosion Resistant Linings. (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 1055: H.M. Stationery Office). Information on German methods of lining metal vessels and tanks with Buna, Igelit, Oppanol, Phenytal, and plates of 65–70% ferrosilicon is given. —R. A. R.

Paints for Coating the Inside of Steam Boilers. O. Retemeyer. (Technik, 1946, vol. 1, Nov., pp. 254–255). The requirements of a paint for the inner surface of steam boilers are discussed. Suitable media are divided into three groups: (*a*) Those made from tar-distillation residues dissolved in low-boiling-point fractions; (*b*) those made from the products of the distillation of brown-coal tars and mineral oils; and (*c*) suspensions of metal oxides in wood tars and linseed oil, and aqueous emulsions. Methods of determining the properties of these materials are described.—R. A. R.

Leaching Rate Tests on Anti-Fouling Compositions. A Testing Method for Inland Stations. N. W. Hanson and R. F. Jervis. (Journal of the Society of Chemical Industry, 1946, vol. 65, Nov., pp. 329–333). A method is described for the determination of the rate at which compounds of the toxic metals copper and mercury leach into sea water from anti-fouling compositions. The method is suitable for stations where sea-water is not directly accessible. Colorimetric procedures for the determination of copper and mercury in sea-water are described, and such aspects as the state in which the toxic metals are dissolved, and the stability of the leachates, are dealt with. The practical implications of the functioning of anti-fouling compositions, and the maintenance of a sufficiently high leaching rate are discussed, special reference being made to the work of investigators at the Woods Hole Marine Biological Laboratories in the United States.—R. A. R.

Drying Industrial Finishes on Metals. H. R. Clauser. (Materials and Methods, 1946, vol. 24, Oct., pp. 910–914, Dec., pp. 1452–1456). The major factors involved in the drying of industrial coatings are discussed. The two processes now generally used, infra-red radiant heating and convection heating, are described in detail, both from the theoretical and practical points of view. The principal advantage of infra-red radiant heating is its ability to concentrate heat directly on the part which is to be heated and so bring it to the required baking temperature in a very short time. Internal heat stresses are avoided, but uneven surface heating may result from variations in the optical properties of the surface. Difficulties arise from the necessity for insulating to conserve heat and at the same time having to provide adequate facilities for the removal by exhaustion of volatile matter released from the finishes. The advantages of convection heating are its uniformity and the wide range of temperatures to which it can be adapted. Its disadvantages are the detrimental effect of products of combustion in the gases upon paints and the time required to bring the oven up to the required temperature.—C. O.

Interferometric Determination of Apparent Thickness of Coatings. W. K. Donaldson and A. Khamsavi. (Nature, 1947, vol. 159, Feb. 15, pp. 228–229). The adaptation of an interferometric method, originally developed for measuring the thickness of deposit from an atomic beam, to the study of evaporated metal films is suggested.—D. R. S.

PROPERTIES AND TESTS

Modern Methods of Testing. A. E. Bingham. (Transactions of the Society of Engineers, 1946, vol. 37, July–Dec., pp. 91–99). The principles and applications of several modern testing techniques are described. These include the use of strain gauges, drop tests, the cathode-ray oscillograph, hydraulics, and photo-elasticity.—R. A. R.

Comparison of Various Structural Alloy Steels by Means of the Static Notch-Bar Tensile Test. G. Sachs, L. J. Ebert, and W. F. Brown, jun. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2110: Metals Technology, 1946, vol. 13, Dec.). The results of static notched-bar tensile tests on three 0·4%-carbon steels containing respectively 3·5% of nickel, 1% of chromium, and 1·81% of manganese, heat-treated and tempered at various temperatures are presented and discussed.—R. A. R.

Some Observations on Tensile Test Curves. J. H. Palm. (Metalen, 1946, vol. 1, Dec., pp. 55–61; 1947, vol. 1, Jan., pp. 85–88). (In Dutch). The relative merits of the ordinary and the true stress-strain curves are considered, with special reference to the use of the reduction in area as a measure of the deformation.—R. A. R.

Work-Hardening and Rupture in Metals. L. R. Jackson. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2072: Metals Technology, 1946, vol. 13, Oct.). The relative importance of shear and hydrostatic stresses in controlling the plastic flow and determining the amount of flow before fracture in metals is discussed, and the use of generalized strains in determining the effect of plastic flow on work-hardening is described. It is considered that the relation between the stress and strain invariants gives a close approximation to the progress of plastic flow in metals, although the effect of hydrostatic stresses is not negligible. The hydrostatic stress components determine the amount of flow and the nature of the fracture. The degree of work-hardening appears to be a function of a strain invariant and to be independent of the stress system producing flow.—C. O.

Connecting Rod Bolt Failures. R. Oxburgh. (The Motor Ship: Australasian Engineer, 1946, Nov. 7, pp. 60–62). The causes and prevention of failures of crankpin bolts in auxiliary Diesel engines are discussed.—C. O.

The Transverse Oscillation of Bars and Fatigue Fracture. P. Matthieu. (Schweizer Archiv, 1946, vol. 12, Nov., pp. 329–338; Dec., pp. 361–372). Methods of calculating the load on a bar subjected to changing transverse oscillations are considered. The solution is closely associated with the stress-time curve. Stress-time curves for a number of cases of practical interest are developed and the position of maximum load is determined. It is shown that the position subjected to the greatest load is not always where one would expect to find it. The nature of the oscillation can be deduced from the position of the fracture.—R. A. R.

Plates in Tension Joints Under Repeated Loading. H. W. Foster. (Product Engineering, 1946, vol. 17, Dec., pp. 108–111). The effects of the design of riveted and bolted joints, the tensile properties of the structural material, and the magnitude of the applied load upon the efficiency of joints in plates subjected to repeated stresses are discussed qualitatively.—C. O.

Magnetostriction of Transformer Steel Subjected to Thermomagnetic Treatment. J. Shur and A. Khokhlov. (Journal of Physics, 1946, vol. 10, No. 6, pp. 540–542). Strips of a cold-worked 4%-silicon transformer steel were annealed and cooled in a magnetic field, and magnetostriction curves were recorded. The magnetostriction for the steel cooled in the absence of a magnetic field was always positive, but for steel cooled in a magnetic field the curve indicated negative values for fields below 25 Oersted and slowly increasing magnetostriction with higher field strengths.—R. A. R.

Theory of the Dispersion of Magnetic Permeability in Ferromagnetic Materials at Microwave Frequencies. C. Kittel. (Physical Review, 1946, vol. 70, Sept. 1 and 15, pp. 281–290). The transition in the value of the initial magnetic permeability of iron and nickel from the d.c. permeability ~ 100 to the infra-red permeability ~ 1 is known to occur principally in the microwave frequency range. An explanation of the experimental facts is proposed by considering the equations of motion of a domain boundary in an applied magnetic field for frequencies such that the skin depth of the magnetic field is smaller than the thickness of a domain. An analytical solution of Maxwell's equations is obtained for the magnetization of a layer one domain in thickness. It is shown that the natural definition of permeability at high frequencies leads to complex values of the permeability. Two types of permeability have been found experimentally. The relationship of the complex permeability to the permeability determined from resistive losses in a circuit element and to the permeability determined from reactance changes is developed. The theories of ferromagnetic resonance and Becker's theory of eddy-current damping are discussed, and suggestions are made for further experimental work.—C. O.

Transmission of Velocity-Selected Neutrons through Magnetized Iron. E. M. Fryer. (Physical Review, 1946, vol. 70, Sept. 1 and 15, pp. 235–244). The increase in the transmitted intensity of slow neutrons through iron with magnetization of the iron was measured using a neutron velocity selector, neutrons of varying velocities, and varying degrees of magnetization. Data for neutrons with a de Broglie wave-length of $2{\cdot}37 \times 10^{-8}$ cm. under different conditions of magnetization have been used to determine the factor by which the increase of transmission is reduced by incomplete magnetic saturation. The use of this factor has enabled the author to calculate the change in iron-neutron cross-section for completely saturated iron for neutrons of de Broglie wave-length $1{\cdot}3$–$3{\cdot}0 \times 10^{-8}$ cm. The fractional change in transmission increased with neutron wave-length, but was three to four times greater than that predicted by Halfern, Hamermesh, and Johnson.—C. O.

The Influence of Hydrogen on Welds made with Coated Electrodes. F. H. Müller. (Elektroschweissung, 1942, vol. 13, Mar., pp. 38–45; Apr., pp. 57–59; May, pp. 71–94). The cross-sections of fractured welded tensile-test specimens made with high-tensile low-alloy electrodes sometimes have peculiar white spots (fish eyes). It is known that these spots are caused by the hydrogen emitted by the casting and absorbed by the molten metal of the weld. The strength of such welds is much below normal. The hydrogen can be removed by annealing at a suitable temperature and welds treated in such a way have a normal structure and strength.—H. O. W.

Measuring the Elastic and Plastic Deformation and the Temperature Field of an Arc-Welded Butt Joint. E. Sudasch. (Elektroschweissung, 1941, vol. 12, Mar., pp. 33–40). The deformation of material in the heat-affected zone of an arc-welded butt joint was determined. The deformation was measured on two lines 6-in. long intersecting at 90°. The temperature of the measuring point was recorded by means of a thermocouple. All measurements were recorded continuously during the whole welding and cooling process. A specially designed extensometer with reflecting mirrors transmitting any variation in length on to sensitive paper is described. The results showed that during the welding and cooling process the material of this zone is subjected to stresses considerably greater than those at the elastic limit.—H. O. W.

Shrinkage Stresses and Plastic Deformation in Welded Structures. E. Gerold and W. Krafft. (Elektroschweissung, 1941, vol. 12, Nov., pp. 173–178). Shrinkage stresses and the zone of plastic deformation were measured in mild steel plates of varying width, welded together by a double-V seam, in plates on which beads had been deposited along the edges, and in a fabricated girder of high-tensile steel. In each case the zone of plastic deformation did not extend for more than 80–100 mm. from the weld. By measuring the variation in length, the stress can be calculated according to Hooke's law. The tensile and compressive stresses increase with increasing width of plates, but only up to 160 mm., *i.e.*, two plates, each 80 mm. wide, butt-welded together. On larger plates the stresses are influenced solely by the amount of heat developed during the welding process.—H. O. W.

Testing of Welded Rails in Rumania. C. Miklósi and S. Nadasan. (Sudura: Elektroschweissung, 1941, vol. 12, July, pp. 111–113). This is a report on comparative tests on welded main-line rails. Two different types of rails weighing 45 and 23 kg./m. respectively were welded by the oxy-acetylene, thermite, and flash-butt-welding processes. The welds were subjected to fatigue tests, to chemical analysis, and to macro- and micrographic tests.—H. O. W.

An Investigation of the Effect of Welding on the Transition Temperature of Navy High-Tensile Low-Alloy Steels. G. C. Luther, C. E. Hartbower, R. E. Metius, and F. H. Laxar. (Welding Journal, 1946, vol. 25, Oct., pp. 634-s–645-s). A description is given of experiments designed to determine the effect of welding upon the temperature at which a change from ductile to brittle fracture occurs in high-tensile low-alloy steels. The

properties of welded and unwelded sheets were compared at various temperatures using Charpy V-notched bars and "high-constraint nick bend" test-pieces. The temperature of transition from ductile to brittle fracture in unwelded plate was raised by welding.—C. O.

Investigation of the Weldability of Copper-Bearing Steels. N. H. Keyser and C. H. Lorig. (Welding Journal, 1946, vol. 25, Oct., pp. 597-s–611-s). A review is made of the literature on the welding of copper-bearing steels, and an account is given of studies on the metal-arc welding of a number of low-alloy wrought and cast sheets to determine the practicability of using copper in place of carbon for producing steels of high strength and superior weldability. Among the conclusions reached were: (1) On the basis of equal tensile properties of the base steel and the welded joints, copper-bearing steels have generally greater notched-bar toughness in all zones of the weld than carbon steels; (2) the heat-affected zone is slightly larger in copper-bearing steels; (3) copper-bearing steels have lower hardenability and the maximum hardness attained in welding them is lower than in comparable carbon steels; (4) the hardness of welded copper-bearing steels is more uniform; (5) copper-bearing steels can be welded in the soft non-precipitation-hardened condition, and later strengthened during a stress-relieving heat-treatment.—C. O.

METALLOGRAPHY

The Utility of Radium in Complex Radiographic Studies. D. H. Wise. (Industrial Radiography and Non-Destructive Testing, 1946, vol. 5, No. 2, pp. 23–26). An illustrated account is given of the use of radium as a source of radiation for the inspection of castings and welds in a shipyard at San Francisco. Radium, while inferior to X-rays from the point of view of definition, contrast, and exposure, is an extremely adaptable means of obtaining radiographs in complex or relatively inaccessible parts.—C. O.

Lattice Structure and the Physical Properties of Metals. W. H. Taylor. (Journal of the Birmingham Metallurgical Society, 1945, vol. 25, Dec., pp. 238–245). Recent work on the relationship between the hardness and lattice structure of primary solid solutions, the lattice stress-strain curve, and the lattice in a heavily-worked metal is reviewed and discussed.—C. O.

X-Ray Microradiography of Distorted Crystals. R. Smoluchowski, C. M. Lucht, and M. Mann. (Physical Review, 1946, vol. 70, Sept. 1 and 15, pp. 318–322). The phenomenon of selective X-ray transmission within single crystals of a metal foil is interpreted as a diffraction effect related to the distortion of the crystal lattice. The distribution and magnitude of the distortions in single crystals have been studied from this point of view.—C. O.

Optical Phenomena with Strongly Etched Metal Foils. W. G. Burgers and J. Weijdema. (Metalen, 1946, vol. 1, Sept. 15, pp. 6–7). (In Dutch). Foils of 50/50 iron–nickel alloy with a thickness of 100μ were etched and X-ray diffraction photographs were taken. These revealed holes the shape of which could be related to the direction in which the original material had been rolled.—R. A. R.

Hot Deformation Structures, Veining and Red-Shortness Cracks in Iron and Steel. A. Hultgren and B. Herrlander. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2106: Metals Technology, 1946, vol. 13, Dec.). Specimens of low and medium-carbon red-short steel were subjected to deformation at temperatures somewhat below and above Ac_3 and the structures obtained were studied under the microscope. The results indicated that: (1) Veining in ferrite is a result of plastic deformation at high temperatures, corresponding to slip lines at lower temperatures. (2) The veining pattern of ferrite varies with temperature and rate of deformation, becoming finer and more regular the quicker the deformation. (3) Deformation of ferrite may be superseded by recrystallization, in which case veining is obliterated. (4) Veining in ferrite during the $\gamma \rightarrow \alpha$ transformation is due to stresses set up during transformation; there may be no veining after very slow cooling through Ar_3. (5) If the steel is quickly cooled immediately after deformation at a high temperature below A_3 the veins etch as grooves, but if the steel is kept for some time at the high temperature, or is cooled less quickly, all veins appear as narrow ridges. (6) As veining is essentially a deformation phenomenon there is little relation between veining and inclusions. (7) In soft steel, hot-shortness cracks almost always form along the grain boundaries of ferrite at below A_3 and of austenite at above A_3.—R. A. R.

Electrical Observations of the Austenite–Martensite Transformation in Steel. A. W. McReynolds. (Journal of Applied Physics, 1946, vol. 17, Oct., pp. 823–833). A method is described for observing the austenite-martensite transformation in steel by measuring electrical resistance. Small wire samples are heated and cooled either in a vacuum or in air while temperature and resistance are automatically recorded. Temperature throughout the sample is uniform enough to permit a determination of resistance as a function of temperature. It is shown that, from these data, a complete record of transformation during cooling can be computed. Such transformation data have been obtained on three steels of widely different compositions, representing the types of steel in which transformation is most difficult to observe.—R. A. R.

Transformation of Austenite in an Aluminium–Chromium–Molybdenum Steel. R. A. Grange, W. G. Holt, and E. T. Tkac. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2109: Metals Technology, 1946, vol. 13, Dec.). The isothermal transformation diagram was constructed for a Nitralloy steel containing carbon 0·41%, nickel 0·17%, chromium 1·57%, molybdenum 0·36%, and aluminium 1·26%. The results of the aluminium addition were: (1) The Ae_1 and Ae_3 points were raised; (2) the temperature range of martensite formation was probably raised; (3) the time required for the austenite to transform was not appreciably affected; (4) the volume of pro-eutectoid ferrite was somewhat increased; and (5) the appearance under the microscope of the intermediate- and low-temperature isothermal transformation products was changed.—R. A. R.

Changes in Steel during Heating. V. N. Svetchnikoff. (Communications of the Kiev Polytechnic Institute, 1945, vol. 4, pp. 49–53). The effect of rate of heating on the position of the Ac_1 point was studied using high-frequency furnaces. Generally the shift increased with rates of heating up to 200–250° C./min., beyond which it remained constant. With a 0·9%-carbon steel having a laminated pearlitic structure, the Ac_1 point shifted a maximum of 45° C., whilst with a grainy pearlite, heated at 1900–2200° C./min. the shift amounted to 80–85° C. The rate of heating does not seem to affect the grain-size, but the physical properties, particularly the limit of proportionality, are reduced.

The solubility of carbon in steels at about 700° C. was measured by metallographic and X-ray methods and by tensile tests. For steels prepared from electrolytic iron plus 0·015–0·51% of carbon it was found to be 0·14–0·16%, whilst for commercial steels with 0·08–0·95% of carbon it was 0·08–0·10%. At high temperatures the

solubilities obtained by X-ray analysis for these two types were 0·07% and 0·06% respectively. The differences between these results from specimens at high temperature and as-quenched are ascribed to the irregular distribution of the carbon within and on the surface of the grains. The rate of quenching has no effect on the amount of carbon retained in solution. —R. A. H.

Non-Diffusional Changes in Alloys during Heating. V. N. Gridnev. (Communications of the Kiev Polytechnic Institute, 1945, vol. 4, pp. 53–54). Non-diffusional changes, *i.e.*, changes in which the lattice is not 'damaged' by diffusion processes, were first observed on copper–aluminium alloys. They are reversible, with a considerable hysteresis, and were found also with iron–nickel alloys. With straight carbon steels, it was impossible to observe the martensite → austenite transformation even at very high rates of heating, but the pearlite → austenite change was studied in sufficient detail, using high rates of heating, which, within certain limits, shifted the critical points. The amount of shift is again connected with the original structure, and it was established by metallographic tests that the $\alpha \rightarrow \gamma$ change is "martensitic" in character. Diagrams of metastable transformations were drawn up and in a number of cases compared with equilibrium diagrams. —R. A. H.

INDUSTRIAL USES AND APPLICATIONS

Carbon and Alloy Steels for General Service Applications. (Metallurgia, 1947, vol. 35, Jan., pp. 130–132). The revised Schedule B.S./S.T.A.5 issued by the Ministry of Supply is reviewed. The schedule was originally prepared as a statement of the general requirements of engineering steels used by the services, in order to simplify production. The revised edition contains additional details of steels included in the original, data on new steels, amplified notes on the selection of steels, and notes on welding methods for steels.—C. O.

Metallurgical Notes. L. Sanderson. (Mine and Quarry Engineering, 1947, vol. 13, Jan., pp. 13–15). A general review of recent developments in the application of ferrous and non-ferrous alloys for industrial purposes is presented.—R. E.

Production Applications of Electronics. (Machinery, 1947, vol. 70, Jan. 16, pp. 76–78). Short explanations are given of the use of electronic controls in regulating the speed and torque of electric motors, resistance welding, and high-frequency induction heating.—C. O.

Care and Maintenance of Wire Ropes. L. Sanderson. (Mine and Quarry Engineering, 1946, vol. 12, Dec., pp. 175–178). A summary is made of the precautions which should be taken to ensure the maximum working life of wire ropes.—C. O.

A Permanent Mold Material. O. Smalley. (Steel, 1947, vol. 120, Feb. 3, pp. 108, 158). The use of Meehanite cast iron for making permanent moulds is discussed. —C. O.

How to Use Statistical Methods in Quality Control. R. J. Davis. (Chemical Engineering, 1946, vol. 53, Dec., pp. 115–117). The use of statistical methods for the purpose of quality control in industry is described, and examples of the use of control charts for process and acceptance control are given.—J. R.

Application of Statistical Methods in Industry. W. T. Rogers. (Steel, 1947, vol. 120, Jan. 20, p. 82). The increasing utilization of statistical methods for quality control in industry is discussed. The use of punched-card tabulating systems and calculating machines has made available an enormous amount of data which it was previously uneconomical to obtain.—C. O.

HISTORICAL

The Development of the Bessemer Process in Lancashire, 1856–1900. W. M. Lord. (Newcomen Society, Jan., 1947, Preprint). An account is given of the early experiments with the Bessemer process. The personal friendship of Bessemer with John Galloway, a Manchester engineer, the activity of certain Lancashire business men, and above all the discovery that the hematite ores of Lancashire and Cumberland were almost the only British ores suitable for acid conversion were responsible for the enormous expansion of the iron and steel industry of Lancashire between 1856, when only four blast-furnaces were in production in the county, and 1883, when the output of Bessemer steel was about a quarter of a million tons.—C. O.

Kirkstall Forge. (Machine Shop Magazine, 1947, vol. 8, Jan., pp. 50–57). A brief history is given of the Kirkstall Forge, which is thought to be the oldest metal-working establishment in England. The mining and smelting of iron was begun by the Cistercian monks of the nearby abbey about 1200 A.D. Today the main activity of the concern is the production of axles, in which 1,800 people are employed.—C. O.

Shrewsbury Letters—A Contribution to the History of Ironmaking. H. R. Schubert. (Journal of the Iron and Steel Institute, 1947, vol. 155, Apr., pp. 521–525). A collection of letters preserved in the Central Library at Sheffield gives information on ironworking on the estates of the Earls of Shrewsbury in the sixteenth and seventeenth centuries. The Manorial Court Rolls of Goodrich Castle contain many details as to ironmaking at that time. Accounts dated 1574 and 1585 report on steel imported to Sheffield for the Earl's use.—R. A. R.

The History of the Iron Industry of the Juras with Special Reference to Iron Ore Smelting at Choindez. M. von Anacker. (Von Roll Mitteilungen, 1945, vol. 4, June, pp. 13–25). The geology of the iron ores of the Juras and the history of their mining and smelting are described with special reference to the early blast-furnaces at Choindez.—R. A. R.

Iron and Steel Industry Progress in the Urals. A. N. Speransky. (Metallurgia, 1946, vol. 35, Dec., pp. 67–68). A short history of the iron and steel industry of the Urals is given. The predominant position which the region attained during the eighteenth century was lost as a result of the Industrial Revolution in Western Europe, but reorganization at the beginning of this century and expansion under the successive Soviet Five Year Plans have succeeded in restoring the industry's prosperity. The iron-ore reserves are as yet not fully explored, but at least 2,500 million tons are known to be present. Only limited supplies of coal are available locally, but high quality coal of low cost is transported by rail from Siberia and Kazakhstan, and the steel produced is the cheapest in the U.S.S.R.—C. O.

ECONOMICS AND STATISTICS

World Steel Production. J. R. Hight. (Iron Age, 1947, vol. 159, Jan. 2, pp. 88–95). The production of steel in the United Kingdom, France, Germany, Belgium, the Netherlands, Czechoslovakia, Sweden, Italy, Canada, Russia, and South America during 1946 is reviewed. Of the major producers, only Russia and the United Kingdom maintained their wartime level of output: production in the United States fell by 23 million tons; Germany produced but one tenth of her pre-war total, and France about one half.—C. O.

British Iron and Steel Industry in 1946. (Iron and Coal Trades Review, 1947, vol. 154, Jan. 10, pp. 55–61). The achievements of the British iron and steel industry

during 1946 are reviewed. The production of pig iron rose from 7,107,400 tons in 1945 to 7,750,000 tons in 1946, and there was a corresponding increase from 11,824,400 tons to 12,690,000 tons in the production of steel. Wages, prices, transport, and the supply of raw materials are discussed briefly.—C. O.

The French Iron and Steel Industry. (British Iron and Steel Federation, Monthly Statistical Bulletin, 1946, vol. 21, Dec., pp. 1–12). Following the announcement of the Monnet Plan for developing the French basic industries, an Iron and Steel Modernization Committee was set up to decide the necessary measures by which the annual production could be raised quickly to 6,000,000 tons of crude steel and 1,000,000 tons of iron castings, this output to rise within five years to 12,000,000 tons and 2,700,000 tons respectively. The present resources of raw materials and plant have been surveyed and details of the production programme are given in comparison with pre-war production. The proposed reorganization of the industry in the Northern and Lorraine basins and the Centre-Midi district is summarized. The cost of the modernization plan is estimated, and it is anticipated that when it has been completed a reduction of about 20% in fuel consumption and an increase in output per man of over 100% will be achieved.—M. A. V.

French Steel Plan. S. H. Kahn. (Iron and Steel, 1947, vol. 20, Jan., p. 26). The recommendations made by the French Steel Commission for the modernization and development of the country's steel industry are summarized (*see* preceding abstract).—C. O.

German Iron and Steel. (British Zone Review : Iron and Steel, 1946, vol. 19, Dec., p. 786). Some of the work in progress, and plans of the British officials for reorganizing the German iron and steel industry are reviewed.—J. R.

Iron and Steel Industry in Spain. L. Barreiro. (Iron and Coal Trades Review, 1947, vol. 154, Jan. 24, p. 194). Data are given for the production of iron ore, coal, and iron and steel in Spain in the period 1929–46. Although several new blast-furnaces were built in 1946, the production of iron and steel is insufficient to meet the demands of home industries.—C. O.

The Foundry Industry and Cast Ferrous Metals. F. J. Walls. (Chicago Engineers' Club : Canadian Metals and Metallurgical Industries, 1946, vol. 9, Dec., pp. 29–30, 40). The position of the ferrous foundry industry in the economy of the United States is discussed.—C. O.

MISCELLANEOUS

Metallurgy as a Profession : Past, Present, and Future. J. W. Jenkin. (Journal of the Birmingham Metallurgical Society, 1945, vol. 25, Dec., pp. 220–237). The development of metallurgy as a profession is traced through the centuries up to the formation of the Institution of Metallurgists.—C. O.

The University Training of a Metallurgist. T. Wright. (Journal of the Birmingham Metallurgical Society, 1946, vol. 26, Dec., pp. 175–193). The considerations which influence the choice of the subjects to be included in a University degree course in metallurgy are discussed. It is manifestly impossible to cover the entire field in the three or four years available, so that a decision must be made as to what can be omitted and what must be included. Since metallurgy is an applied science, the basis for this decision should be not the purely academic point of view which regards the subject as a branch of learning to be studied solely for the sake of knowledge, but the utilitarian point of view which recognizes that the student is to be trained for a profession. The criterion for rejection and selection is then the advantage which may be derived by the student from his knowledge of a particular subject during his subsequent career in industry.

In Great Britain, iron is the only metal extracted on a large scale, so that undue emphasis need not be placed on extraction processes, thus allowing more time to be devoted to the study of metal processing and the properties and uses of alloys, with which British industry is mainly concerned. Men have to be trained for a wide variety of jobs between the extremes of works management and pure research, but narrow specialization has several disadvantages. It is thought that the system adopted at Birmingham University affords a very satisfactory compromise.—C. O.

Metals in Modern Society. C. S. Smith. (Mining and Metallurgy, 1946, vol. 27, Nov., pp. 541–543). The relationship between the state of metallurgical knowledge and the progress of civilization is discussed. Until the beginning of the twentieth century metals and alloys could be produced with properties surpassing those required by the engineer, and in sufficient quantity, but since then the demands of designers have far outstripped metallurgical advances. Metallurgy is still considered as an art, in which skill and empirical knowledge outweigh scientific understanding. A wealth of experimental data exists which, if correlated, may enable general principles to be formulated so that in the future theoretical knowledge will precede application, and not follow it, as in the past.—C. O.

Recent Developments in Water Treatment. E. L. Streatfield. (Transactions of the Liverpool Engineering Society, 1946, vol. 67, pp. 80–98). Recent developments in the treatment of water for domestic and industrial use by coagulation, sedimentation, filtration, and softening are reviewed.—C. O.

Scrap Salvaging. (Steel, 1947, vol. 120, Feb. 3, p. 118). A short account is given of the arrangements for salvaging scrap in the relatively small Baltimore works of the Westinghouse Electric Corporation.—C. O.

BOOK NOTICES

BREARLEY, H. "*Talks About Steelmaking.*" 8vo, pp. 236. Cleveland, Ohio, 1946 : The American Society for Metals. (Price $3.50).

The author of this book needs no introduction to those associated with the steel industry, and particularly to those who have been engaged therein for some time.

The title has been aptly chosen, seeing that, according to the preface, the "chapters may be read in any sequence" and "there has been no striving to make a continuous story." Although each chapter is a separate talk, there is, however, a central theme, namely, that steelmaking is a highly skilled craft and, further, that the craft should not be regarded apart from the craftsman.

Seven of the thirteen chapters deal with molten steel, melting processes, forging, testing steel, notch fractures, making specifications, and clean steel—a blending of history, science, technology and philosophy, interspersed with real humour. One example of the humour illustrates its aptness, and this has been taken from the section dealing with flaking in the chapter on melting processes: "Flaking steel is an affliction on those who make alloy steels and use electric melting-furnaces; and, like lumbago, it strikes the sufferers unexpectedly and without reason." Lecturers should find food for thought in the methods adopted by the author in producing this blend, and if perchance they find the interest of their students is declining, they might try this method as a remedy.

The remaining six chapters entitled "Beginnings," "The Job's the Boss," "Complaints," "Remunerations," "Helpful Comparisons" and "Scrapalurgy," are a judicious mixture of common sense and a psychological understanding of both makers and users of steel. In "Beginnings" the scene of operations is the laboratory with chemical apparatus and a microscope in the foreground. The purpose of encouraging beginners to experiment is to lead them to "know how" and "know why."

Problems arising between producer and customer are generally capable of solution if the right methods of approach are adopted, and the chapter entitled "Complaints" is an excellent example of the application of psychology. It would also serve as a good guide to those aspiring to become efficient salesmen.

The author has coined the word "scrapalurgy" for the concluding chapter, a word which he says nearly defines itself. He continues with the statement that "the subject is a slippery one because it is an art, a science, a trade and an aspect of domestic economy." This chapter, like the rest of the book, is packed with common sense and with practical issues that have a direct bearing on present-day problems.

It is impossible to read this book without realising the extent to which, from practical experience, the author views steelmaking as an attractive occupation. It reveals, in addition, his deep understanding (and indeed affection) for all engaged in the industry, from the fully qualified craftsman to the beginner who needs both encouragement and guidance.

G. PATCHIN.

SEARS, F. W. "*Principles of Physics.*" Vol. I: "*Mechanics, Heat and Sound.*" Pp. 526. Illustrated. Vol. II: "*Electricity and Magnetism.*" Pp. 410. Illustrated; Vol. III: "*Optics.*" Pp. 323. Illustrated. Cambridge, Mass.: Addison-Wesley Press, Inc. (Price, Vols. I and II, $5.00 each, Vol. III, $4.00).

The title of this book has been chosen deliberately to indicate that its emphasis is on physical principles. Historical background and practical applications have been given a place of secondary importance. Many of the problems in the book are taken from examinations held in connection with the physics course at the Massachusetts Institute of Technology.—R. E.

WISSMANN, C. C. "*Acid Electric Furnace Steelmaking Practice.*" Sm. 8vo, pp. 84. Cleveland, Ohio, 1947: The American Society for Metals.

The purpose of this booklet is to present a simple set of instructions primarily as an aid to those engaged in the operation of acid electric steelmelting furnaces. All the problems discussed deal with the operation of the furnace and the process of steelmaking.—R. E.

NEW PUBLICATIONS

ALLAN, R. K. "*Rolling Bearings.*" Second Edition. London: Sir Isaac Pitman and Sons, Ltd. (Price 30*s.*)

AMERICAN SOCIETY FOR METALS. "*Heat Treatment of Metals.*" Cleveland, Ohio. (Price $3.00).

"*Bergbau-Archiv.*" Gesammelte Beiträge aus Wissenschaft und Praxis des Bergbaus. Band. I. 8vo, pp. 244. Essen-Ketturg, 1946: Verlag Glückauf G.m.b.H. (Price 15 RM.)

ECKEL, J. F. and R. J. RAUDEBAUGH. "*Laboratory Manual in Metallography.*" 8vo, pp. viii + 344. New York, 1946: McGraw-Hill Book Co., Inc.; London: McGraw-Hill Publishing Co., Ltd. (Price 22*s.* 6*d.*).

GUINIER, A. "*Radiocristallographie.*" Pp. ix + 294. Illustrated. Paris, 1945: Librairie Dunod. (Price 725 francs).

HOEK, A. G. v. d. "*Metalen en Leringen.*" 4e druk. Pp. 242. Rotterdam: Nygh and van Ditmar N.V. (Price Fl. 7.50).

IRON AND STEEL INSTITUTE. Special Report No. 34. "*First Report of the Rolling-Mill Research Sub-Committee of the Iron and Steel Industrial Research Council.*" 8vo, pp. 146. Illustrated. London, 1946: The Institute. (Price 10*s.*, Members 5*s.*)

IRON AND STEEL INSTITUTE. Special Report No. 35. "*Second Report on the Development of Monolithic Dolomite Linings.*" 8vo, pp. viii + 140. Illustrated. London, 1946: The Institute. (Price 16*s.*, Members 10*s.*)

IRON AND STEEL INSTITUTE. Special Report No. 36. "*Symposium on the Hardenability of Steel.*" 8vo, pp. ix + 430. Illustrated. London, 1946: The Institute. (Price 16*s.*, Members 10*s.*)

JOHNSON, F. "*Metal Working and Heat Treatment Manual.*" Volume II. "*Alloy Steels, Cast Iron and Non-Ferrous Metals.*" London: Paul Elek (Publishers) Ltd. (Price 17*s.* 6*d.*)

LEVASSEUR, A. "*L'Electrochimie et L'Electrométallurgie.*" Tome I. "*Electrolyse.*" Tome II. "*Fours électriques.*" Paris, 1947: Dunod. (Price, vol. 1, 280 francs; vol. 2, 330 francs).

SOLLBERG, H. L., O. C. CROMER and A. R. SPALDING. "*Elementary Heat Power.*" 8vo, pp. 480. New York: John Wiley and Sons, Inc. (Price $4.75).

"*Watkin's Cyclopedia of the Steel Industry.*" Pittsburgh: Steel Publications, Inc. (Price $11.00).

WISSMANN, C. C. "*Acid Electric Furnace Steelmaking Practice.*" Sm. 8vo, pp. 84. Cleveland, Ohio, 1947: The American Society for Metals.